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COST ANALYSIS OF ELECTRONIC TABULAR DISPLAY SUBSYSTEM.(U)

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DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

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16. Abstract

This report documents work performed by SRI International for the Federal Aviation Administration to study the potential cost-effectiveness of implementing Electronic Tabular Display Subsystems (ETABS) in the en route air traffic control system. ETABS is a device to electronically present flight data to air traffic controllers, and would automate certain control tasks. Cost comparisons are made for National Airspace System (NAS) Stage A system operations both with and without ETABS. Included for both operational systems are estimates of the present value of FAA expenditures during the fiscal years 1977 through 1999 for staffing, engineering and development, facilities and equipment, maintenance, and training; costs relating to delay, accidents, and the like are not included. Staffing costs, which account for the major portion of the total expenditures examined, represent wage costs for Air Traffic Service controller and support personnel and for Airway Facility Service personnel. Controller staffing includes full performance level and developmental personnel, with allowances for advance recruitment needs. Computerized modeling techniques used to estimate staffing include the Relative Capacity Estimating Process (RECEP); Air Traffic Flow (ATF) network simulation, and Controller Advance Recruitment (CAR) routines. Results find that ETABS deployment would obtain cost savings relative to continuation of the current NAS Stage A system. ETABS cost avoidances are shown to result from various sensitivity analyses of the costs estimation procedures.

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ABBREVIATIONS

A	assistant
AAF	Airway Facilities Service
AAT	Air Traffic Service
A/G	air/ground
APT	Office of Personnel and Training
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATF	Air Traffic Flow
CAR	Controller Advance Recruitment
CCC	Central Computer Complex
CRD	computer readout device
CRT	cathode ray tube
D	data
DSS	Data System Specialist
DYSIM	
E&D	engineering and development
ETABS	Electronic Tabular Display Subsystems
FAA	Federal Aviation Administration
FDP	flight data processing
F&E	facilities and equipment
FPL	full performance level
FSP	flight strip printer
FY	fiscal year
NAFEC	National Aviation Facilities Experimental Center
NAS	National Airspace System
PVD	plan view display
R	radar
R and D	research and data
RDP	radar data processing
RECEP	Relative Capacity Estimating Process

SRDS System Research and Development Service

T tracker

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We also wish to identify and acknowledge the contribution of the various SRI staff members who participated in this study. The study effort was performed under the direction of Mr. Stephen J. Petracek and the supervision of Dr. George J. Couluris. Mr. H. Steven Procter and Ms. Rilla Reynolds were responsible for the modification and operation of SRI's Air Traffic Flow Model. This work was performed in SRI's Transportation Center, which is directed by Dr. Robert S. Ratner.

EXECUTIVE SUMMARY

This report, prepared by SRI International (formerly Stanford Research Institute) for the Federal Aviation Administration, analyzes the cost-effectiveness effects of implementing Electronic Tabular Display Subsystems (ETABS) in the national en route air traffic control (ATC) system. ETABS cumulative cost estimates for FY 1977 through 1999 are compared against those costs associated with the continuation of the current National Airspace System (NAS) Stage A system through the same period. The costs analyzed are the 1976 present values of FAA expenditures for staffing, training, engineering and development (E&D), facility and equipment (F&E), and maintenance; costs relating to delay, accidents, and the like are not included. Staffing expenditures are the wage costs for air traffic controller and other Air Traffic Service (AAT) personnel and Airway Facilities Service (AAF) personnel. The current NAS Stage A system and ETABS system costs are developed and compared for ATC operations at the 20 domestic air route traffic control centers.

Method of Approach

ETABS is an electronic flight data presentation located at en route sector positions, and is designed to replace the paper flight strips used currently as part of the NAS Stage A system to maintain aircraft flight plan information. ETABS would effectively automate some controller manual and verbal tasks, and thereby reduce controller workload routinely required for each aircraft. The reduced workload per aircraft together with a redistribution of work among sector controller team members would enable sectors equipped with ETABS to handle more aircraft with fewer controllers than the same sectors equipped with flight strips.

The number of controllers required for both current NAS Stage A and ETABS sector operations are the primary influences on the cost comparisons in the research. The estimation of controller staffing occupied a major portion of this research effort. The controller staffing estimates for the 20 centers included herein are based on refinements to modeling techniques developed during previous SRI case studies of Los Angeles Center and Atlanta Center operations. Noncontroller staffing estimates and cost estimates are based on data developed by the FAA. These data include staffing standards and guidelines for other AAT and AAF personnel; staff wage costs; and E&D, F&E, maintenance, and training program costs.

The controller staffing estimation procedure used three computerized models developed by SRI:

- Relative Capacity Estimating Process (RECEP)

- Air Traffic Flow (ATF) network simulation model
- Controller Advance Recruitment (CAR) model.

RECEP and ATF are used to estimate controller annual staffing requirements during the FY 1977 through 1999 study period for the Los Angeles and the Atlanta Centers. These requirements estimate the minimum number of controllers needed to operate each facility for both the current NAS Stage A and the ETABS systems. The requirements are parameterized in terms of staffing growth versus traffic growth factors. The average of the controller requirement parameters obtained for the two case study sites is used to represent national controller requirement parameters for the 20 centers. CAR then is used to estimate actual controller annual staffing by accounting for advance recruitment and training needs. To supplement the CAR-derived data, noncontroller AAT and AAF staffing are calculated using FAA staffing standards and guidelines.

RECEP Application

Data collected at the two centers during the previous case studies are used to construct workload models of sector team task requirements. Tasks include decision making, air/ground (A/G) voice communications, computer data entry and display manual operations, flight strip processing manual operations, and interphone and direct (face-to-face) voice communications. These RECEP workload models quantify workload and traffic capacity relationships for selected sectors under the observed NAS Stage A operations. Task workload parameters in RECEP models are judgmentally adjusted to represent ETABS sector operations. The RECEP models obtain sector traffic capacity estimates for alternative team manning and sectorization strategies for the current NAS Stage A and ETABS systems.

ATF Application

The RECEP-defined sector traffic capacity estimates are used in the ATF network simulation to determine the multisector traffic handling and delay characteristics associated with both systems. ATF enables examination of alternative sector configuration strategies (based strictly on sector splits) and alternative sector manning strategies (based on increasing or decreasing the number of sector team positions when feasible) in order to estimate the number of day-shift, busy-day controllers needed in selected multisector regions of the Los Angeles and Atlanta Centers by each system as traffic is projected to increase. These controller estimates are based on the number of sectors and controllers needed to maintain baseline 1976 average aircraft delay, except for those situations where manning and sectorization constraints restrict staff expansion. In the latter case, controller staff growth in response to traffic growth is constrained, and average delays to aircraft increase beyond baseline levels. The day-shift manning requirements for the two case study sites

are expanded to annual controller staffing requirement parameters--by accounting for midnight and evening shift, weekend, relief, and annual sick leave needs. From this, the national annual controller staffing requirements for the 20 domestic centers are calculated for specific annual traffic growth projections.

CAR Application

The annual staffing requirements define the minimum number of controllers needed to operate active sector positions. The current NAS Stage A system's sectors include the radar (R), data (D), tracker (T), and assistant (A) positions, while ETABS sectors include R and D positions. The estimated controller requirements alone do not account for the number of developmental controllers that must be hired in advance of staffing requirements and must be trained into full performance level (FPL) controllers. The CAR model estimates the advance recruitment of the developmental controllers needed during successive quarters of each year of the study period. The CAR formulation used in this analysis assumes a four-year training program, during which each developmental controller progressively qualifies for A, D, T, and R position operations. Allowances are made for developmental controller wash-outs from the training program and normal attrition of FPL controllers. The resulting controller staffing estimate for a quarter is the sum of controller staffing remaining from the previous quarter and the advance recruitment needed to meet future staffing requirements. Total annual staffing is determined by using FAA standards and guidelines to calculate noncontroller AAT staffing requirements (which depend in part on the number of controllers) and AAF staffing requirements (which depend in part on the number of operating sectors), and adding these staffing estimates to those for controllers.

Results

The combined AAT and AAF staffs projected for the 20 centers over FY 1977-99 for current NAS Stage A continuance and base case ETABS deployment plans are compared in Figure 1. These projections correspond to a traffic forecast provided by the FAA.

NAS Stage A Staffing

Staffing for the current NAS Stage A system is shown to increase from 11,990 persons (including 7,468 controllers) at the end of the FY 1976 baseline year to 20,784 persons (14,740 controllers) by the end of FY 1999. This growth pattern includes a rapid increase in staffing to 16,000 persons by the start of FY 1983, after which staffing continues to increase but at a lower growth rate. From FY 1977 through 1982, all centers are assumed to expand staffing by adding new sectors or increasing sector team manning or both. But by FY 1983, some centers reach their sectorization and manning limits and cannot further expand staffing although

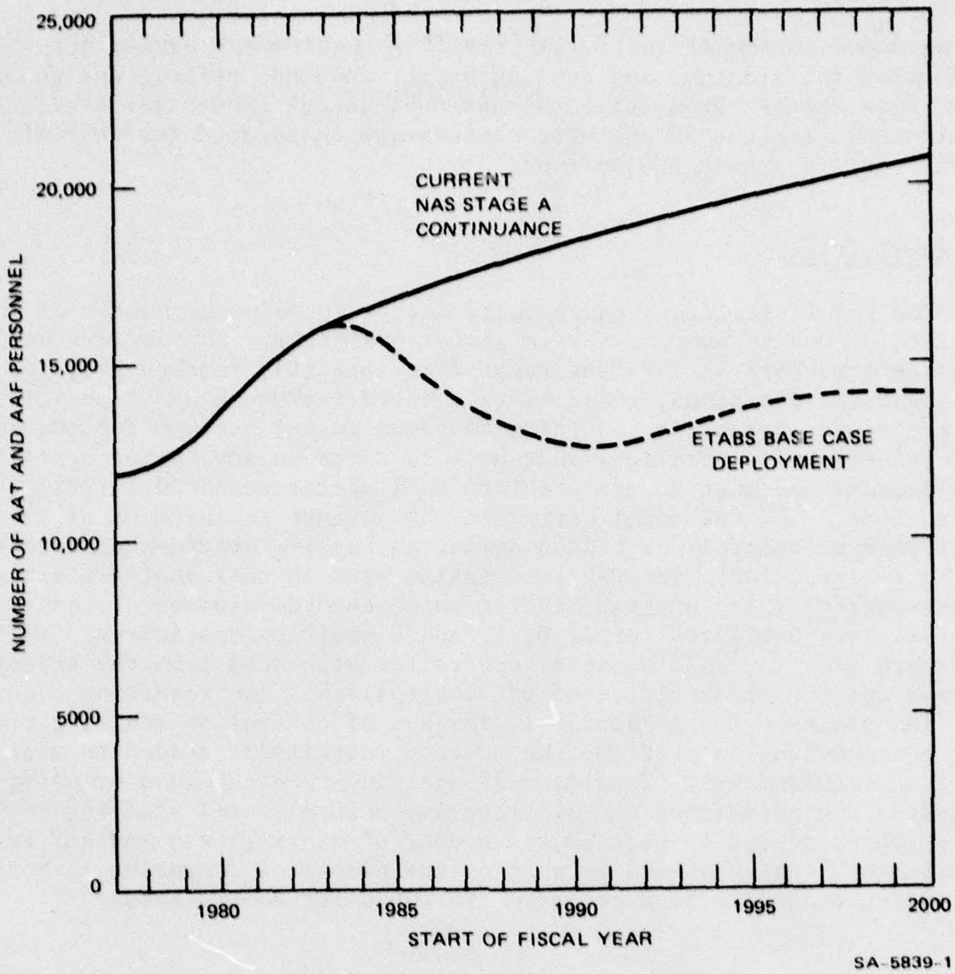

FIGURE 1 STAFFING ESTIMATES

other centers are able to increase their staffing. The tapering off of staffing during and after FY 1983 in Figure 1 indicates the inability of some centers to respond to traffic growth under current NAS Stage A system operations due to reaching a limit on the number of sectors that can be formed.

From the analysis of current NAS Stage A continuance it was estimated that the number of operating sectors would grow from 660 at the end of 1976 to a maximum limit of 1,201 at the start of 1992. With the current NAS Stage A system, staffing will continue to grow during and after 1992 because of increased sector team manning. Such staffing growth will be achieved, for example, by adding the T controller to the R, D, and A controller team; the latter team manning strategy typifies baseline 1976 operations.

Base Case ETABS Staffing

The base case ETABS deployment assumes that engineering and development of equipment will be completed by FY 1980, initial procurement will occur from FY 1982 to 1985, and operational deployment of sector positions will be half completed during FY 1984 and fully implemented by the end of FY 1985. Full ETABS sector operations are assumed thereafter, but with current NAS Stage A system equipment held as back-up for two years.

RECEP and ATF analysis of ETABS effect on sector workload and manning revealed that R and D controller traffic handling capacities would increase relative to their current NAS Stage A system capabilities, and that the T and A positions would not be required. As a result, fewer ETABS sectors and fewer controllers per ETABS sector will be needed to handle a given level of traffic than are required by current NAS Stage A system sectors. The effect on advance recruitment by these reductions in sector and sector manning requirements are shown in Figure 1, where ETABS staffing begins to decrease from 16,102 persons at the start of FY 1983. In this case, the number of sectors are assumed to decrease, but the size of the controller work force would be reduced only through normal washout and attrition. A transition from 970 current NAS Stage A system sectors at the start of 1984 to 741 ETABS sectors at the end of 1985 is estimated. The CAR modeling of staffing shows a continual attrition of the work force until FY 1991, where traffic growth causes staffing to increase. Staffing growth with ETABS during the 1990s is based on increasing the number of sectors until the maximum sectorization limit of 1,201 sectors is reached at the start of 1999. ETABS staffing at end of FY 1999 is 14,128 persons (8,969 controllers).

Costs Comparison

The present values of the estimated cost items associated with current NAS Stage A continuance and base case ETABS deployment are listed in Table 1. A total cost savings of $433.7 million accumulated during the FY 1977-99 is attributed to the ETABS deployment.

The staffing dollars shown in Table 1 represent wage costs for AAT controllers (developmental and FPL), other AAT personnel (support and management), and AAF personnel (technician, support, and management). Staffing reductions in all three categories are obtained by ETABS implementation, resulting in a combined staffing cost savings of $428.9 million. The controller staff accounts for 77 percent of this savings and is the major cost factor of the items listed in Table 1.

E&D costs are assigned only to ETABS, since NAS Stage A has been developed. F&E costs represent equipment procurements needed for additional NAS Stage A sectors (beyond those in existence during the 1976 baseline year), and the initial procurement lot of 1,000 ETABS sector consoles in the early to mid 1980s as well as subsequent procurements. The combined E&D and F&E costs for ETABS deployment are greater than those for current NAS Stage A continuance, but decrease the cost savings

Table 1

COMPARISON OF BASE CASE COSTS

Cost Item	Present Value Costs and Savings (millions of 1976 dollars)		
	NAS Stage A Costs	ETABS Costs	Savings
Controller staff	$2,361.5	$2,032.8	$328.7
Other AAT staff	636.0	559.9	76.1
AAF staff	554.8	530.7	24.1
E&D costs	0.0	3.0	-3.0
F&E costs	63.1	82.2	-19.1
Maintenance	230.9	209.0	21.9
Training	17.7	12.8	4.9
Total	$3,864.1	$3,430.4	$433.7

attributable to ETABS by an amount equal to only 5 percent of the staffing cost savings.

Maintenance costs include those for parts replacement and repair. ETABS maintenance cost savings are due largely to reduced requirements for telephone key equipment. Training costs represent the establishment of training courses and related travel requirements, but do not include wage costs for center personnel (which are accounted for in staffing costs). Reduced travel costs for fewer new hires account for the ETABS training cost savings.

The staffing cost savings account for 99 percent of the total cost savings identified as ETABS benefits. Additional ETABS cost savings would have been quantified if aircraft delay had been counted. Because ETABS sector teams would be able to handle more aircraft per controller than could current NAS Stage A sectors, the constraining effects of sectorization limitations on staffing growth would defer the build up of delays under ETABS operations.

Sensitivity Analysis

Table 2 summarizes the cost analysis results obtained by varying selected assumptions included in the base case ETABS deployment. In all the cases shown, ETABS implementation is shown to achieve cost savings relative to NAS Stage A continuance.

Table 2

SENSITIVITY ANALYSES SUMMARY

Sensitivity Analysis Description	Present Value Costs and Savings (millions of 1976 dollars)		
	NAS Stage A Costs	ETABS Costs	Savings
Base case	$3,864.1	$3,430.4	$433.7
10% sector reduction allowed	3,864.1	3,445.2	418.9
0% sector reduction allowed	3,864.1	3,524.1	340.0
D-controller four-year training schedule	3,864.1	3,441.8	422.3
Three-year deferral of ETABS	3,864.1	3,594.2	269.9
50% decrease in traffic increase	3,380.5	2,938.3	442.2
50% increase in traffic increase	4,169.0	3,738.7	430.3
25% increase in staffing costs	4,752.2	4,211.3	540.9
25% increase in E&D and F&E costs	3,864.1	3,451.7	412.4
No controller workload reduction	3,864.1	3,721.2	142.9
Peaked traffic profile	4,181.8	3,701.5	480.3

The sector reduction sensitivity analyses in Table 2 refer to the transition from the current NAS Stage A system to ETABS sectors during FY 1984 and 1985. The zero percent sector reduction assumes that no sectors are eliminated during the transition, and that all current NAS Stage A system sectors in existance at the start of FY 1984 are converted into ETABS sectors. Also examined is the allowance of an annual 10 percent reduction in the number of sectors during the 2-year NAS Stage A to ETABS transition.

The D-controller training schedule sensitivity analysis in Table 2 refers to the base case assumption that 2 years are required before a developmental controller is qualified to operate a D position. This assumption corresponds to the current NAS Stage A training curriculum. The D-controller cost sensitivity results shown in Table 2 assume that a developmental controller does not qualify for D-position operations until the last year of the four-year training program (which is the case for R-position qualification).

In the next sensitivity analysis shown in Table 2 (3-year deferral of ETABS), ETABS implementation is assumed to be deferred 3 years after the

FY 1984-85 base case implementation schedule. This deferral reduces the staffing cost savings realized in the base case ETABS deployment. However, cost reductions are still sufficient to effect total cost savings, even with the assumption that E&D costs are not delayed or reduced from their base case estimates. Adjustments shown in Table 2 to the base case traffic forecast, staffing wage costs, and E&D and F&E costs similarly demonstrate a cost savings resulting from ETABS deployment.

Despite the modeling analysis conclusions indicating that work-load reductions and sector traffic capacity per controller would increase as a result of ETABS, a cost sensitivity analysis was conducted that assumed no such gains would be achieved. This assumption severely restricted ETABS operational benefits solely to those associated with the elimination of the A-position staffing, yet total cost savings were still obtained, as indicated in Table 2 opposite "no controller workload reduction."

All the previous sensitivity analysis cases, including the base case, assumed that the traffic peaking profiles characteristic of current traffic demand would be supressed as traffic is projected to grow. This smoothed traffic profile is representative of future regulatory or voluntary constraints to current scheduling practices. An alternative traffic projection profile, which maintains the current peaking characteristics, would accelerate current NAS Stage A system and base case ETABS staffing, but would still achieve ETABS cost savings--as shown in the last line of Table 2.

I INTRODUCTION

A. Objectives and Scope

This report documents SRI International's evaluation of the economic desirability of the further development of an Electronic Tabular Display Subsystem (ETABS). The evaluation was performed for the Office of Aviation Policy, Federal Aviation Administration (FAA), under Contract DOT-FATTWA-3911; it was coordinated with the Air Traffic Control (ATC) Systems Division, Systems Research and Development Service, FAA. The principal objective of this study was the development of reliable projections of the costs associated with the implementation of ETABS at the 20 Air Route Traffic Control Centers (ARTCCs) in the conterminous United States. Comparing these costs to the FAA costs projected through the continued operation of the current National Airspace System (NAS) Stage A en route Air Traffic Control system allowed the determination of the ETABS-related savings. The costs included for comparison are the expenditures for controller staffing, other Air Traffic Service (AAT) staffing, Airway Facilities Service (AAF) staffing, engineering and development (E&D), facilities and equipment (F&E), maintenance, and training. The study period for which these costs and savings were projected is from fiscal year (FY) 1977 through FY 1999, inclusive. All expenditures are discounted at a 10 percent rate to their start of FY 1976 present worth values to permit comparisons with other recent cost studies.

Separate work areas within this study include:

- Formal definition and description of the salient operational characteristics of both the NAS Stage A system with and without ETABS.
- Estimation of the basic changes to controller workload and productivity expected to occur because of ETABS implementation.
- Development of the functional relationships between controller workload and productivity, traffic activity levels, and staffing requirements for the current NAS Stage A system and the ETABS system.
- Projection of annual FAA staffing (including advance recruitment) and expenditure levels for the period FY 1977-99, both for current NAS Stage A system continuance and ETABS system deployment.
- Analysis of the sensitivity of the projections of staffing and expenditure levels.

B. Background

The paper flight progress strip has been the basic method of posting flight data information since the inception of the Air Traffic Control system in the 1930s. Basic identification, time, and location-status information about individual flights was initially entered manually, then updated by pencil on these paper flight strips. With the advent of computer flight data processing (NAS Stage A), electromechanical flight strip printers (FSPs) were installed in the ARTCCs to initially prepare flight progress strips for each sector and to distribute additional flight data information to the appropriate en route sectors within the ARTCCs. However, the controllers are still required to manually remove new and updated paper flight strips from the printers, separate them, mount them in flight strip holders, sequence them, and update the information on them. The modification of outdated flight progress information often requires that the controllers perform dual entry activities: writing the updated information on the paper flight strip and also inputting it into the NAS Stage A Central Computer Complex (CCC) through the use of data entry devices, such as keyboards, located at each sector. In addition, the input of information changes into the CCC can cause the updated information to be routed to other control sectors, thereby requiring controllers at those sectors to manually update their flight strips. These activities consume much of the controller's time and cause work that is not always perceived as being directly associated with the air traffic control task of maintaining aircraft separation.

It has been postulated that much of the controller workload associated with flight data activities could be reduced or eliminated through the implementation of an electronic information display interfaced with the ATRCC's CCC. The FAA's ETABS program has been established to investigate the development and deployment of such a system. The objectives of ETABS are to increase controller efficiency and productivity by (1) eliminating the manual handling of paper flight strips by sector controllers, (2) eliminating the manual modifications and updating of paper flight strips by sector controllers, (3) reducing the controller's workload of data entry to the ARTCC computer system, and (4) providing additional information at the data (D) controller position (for example, Mode C altitude data).

C. Method of Approach

The major portion of this effort entailed the estimation of annual staffing costs for FY 1977 through 1999. Basic cost and schedule data for engineering and development, facilities and equipment, maintenance, and training were provided by the FAA.

The staffing estimation is based on ATC analysis capabilities developed by SRI International during two case studies previously conducted for the FAA.[1-4]* The first case study[1] addressed en route operations at

*References are listed at the end of this report.

the Los Angeles ARTCC. As part of this study, SRI conducted field observation and data collection efforts at the center during June 1974, and developed analytical and computer models of ATC operations for the observed NAS Stage A system and postulated future automated systems. The models included the Relative Capacity Estimating Process (RECEP), which relates controller work-load requirements to sector traffic capacities, and the Air Traffic Flow (ATF) network simulation model, which assesses traffic capacity and delay in a multisector environment. A similar case study[2] analyzed operations at the Atlanta Center using data collected by SRI during December 1975, during which the NAS Stage A system was in operation.

For both case studies, the RECEP and ATF models were used by SRI to estimate staffing effects of various automation systems, including ETABS. In doing so, a number of assumptions and judgments were made regarding the feasibility of implementing the postulated enhancement features in an operational en route ATC environment. The models of controller workload encoded the assumptions made regarding the way in which each of the enhancement systems might be implemented. In some cases, these views did not conform in all details to the various designs postulated by specialists in the FAA[5] or elsewhere,[6] but the staffing analyses required operational descriptions that were both realistic and consistent with the current en route ATC development programs. Where these descriptions were not available in sufficient detail, the necessary operational procedures were developed.

The estimation of staffing in this report employs the basic techniques developed during the two case studies, but with refinements to the estimation methodology. "Controller staffing requirements" was estimated using updated versions of the RECEP and ATF models. Controller staffing requirements, in this study, is the minimum number of controllers needed to operate the control positions (including daily and weekend shifts, relief, and annual and sick leave needs) and excludes supervisory, support, training, and maintenance needs. "Controller staffing" was estimated by making allowances for the advance hiring and training needed to satisfy the controller staffing requirements. These staffing allowances were calculated by a computerized Controller Advance Recruitment (CAR) model developed by SRI specifically for this project. The inclusion of advance recruitment is the main refinement to the methodology previously used during the case studies.

The controller staffing estimates are determined for specific forecasts of traffic for each year during FY 1977 through 1999. A second refinement used in this study developed traffic situations characterized by either severe peaking or by smoothing of the traffic peaks. Staffing estimates were determined for both the peaked and smoothed traffic projections to enable a comparison of traffic loading effect on current NAS Stage A and ETABS operations and costs.

However, once the controller staffing requirements are estimated (using RECEP and ATF) and the controller staff is determined (using CAR),

the FAA staffing standards can be used to determine the manning needed for supervision, support, training, and so forth. In addition, the FAA furnished supplementary data concerning maintenance staffing and costs, and special training staffing and costs; wage costs by position; facility and equipment costs and schedules; engineering and development costs and schedules; and a schedule for ETABS equipment implementation in FY 1984-85. These data were integrated with the staffing estimates, so that the discounted total costs resulting from ETABS deployment could be compared with the continuance of the current NAS Stage A system.

Analyses were conducted concerning the sensitivity of total costs to revised traffic forecasts, deployment plans, wage costs, engineering and development costs, facility and equipment costs, and workload modeling assumptions.

D. Organization of this Report

The remainder of this report describes in greater detail the research approach and findings. This description is generally separated into the major functional work areas. Section II gives an operational overview of the NAS Stage A system with and without ETABS, summarizing the operational characteristics of both. The information presented in this section is useful for persons who may be unfamiliar with the ATC operational environment, but may be skimmed, or even skipped, by more knowledgeable persons. Section III describes the method of approach used to estimate the minimum controller staffing requirements for current NAS Stage A and ETABS operations. Section IV describes the methods and assumptions used to develop projections of the national staffing levels for the study period of FY 1977-99. Section V describes projections of the costs associated with current NAS Stage A System continuance and ETABS deployment systems during the study period. Section VI describes the sensitivity analyses that were performed as part of this study. A summary description of the study's method of approach, results, and conclusions is presented in the Executive Summary located at the beginning of this report.

II OPERATIONAL OVERVIEW

This section describes and compares the salient characteristics of sector control operations for the NAS Stage A system with and without ETABS. The reader who is familiar with en route operations and ETABS operational effects may proceed to Section III.

The description of the NAS Stage A operations without ETABS is based on previous observations and data collection sessions at the Los Angeles and Atlanta Centers; these efforts were part of the two SRI case studies[1,2] of potential effects of en route ATC automation. The ETABS operational description is an estimate of how ETABS implementation would affect sector controller activities (that is, alter current control work characteristics) and is based in part on SRI discussions with facility controllers concerning ETABS feasibility as well as on available FAA documentation.[5,6] More detailed descriptions are contained in the case study reports,[1,2] parts of which are included in the appendixes to this report.

The following descriptions address system equipment, controller responsibilities, and manning for en route facilities.

A. NAS Stage A Operations

The en route airspace controlled by an ARTCC facility is divided into volumes of airspace called sectors. Each sector is under the jurisdiction of a controller or team of controllers who maintain radio contact with and radar surveillance of aircraft within the sector. Sectors are configured according to a system of high, low, and transition (for airport arrivals and departures) routes, and the control operations for each sector are procedurally structured and integrated with each other to facilitate traffic flow and separation assurance.

Sector teams are grouped into areas, each of which is administered by a team supervisor. A flow controller and (military) mission coordinator are responsible for traffic coordination for the center, while a data systems specialist coordinates computer programming operational support. An assistant chief supervises all traffic control activities. In addition to these Air Traffic Service personnel (including controllers) located in the control room, a systems engineer (Airway Facilities Service) coordinates maintenance operations. Additional supervisory, programming, and maintenance personnel support control room operations.

The responsibility for safe and efficient control of air traffic resides in the sector control operation, which is the focus of our discussions in the remainder of this section. In order to provide an overview of the en route ATC operational environment we will describe, first,

the control procedures used to integrate sector control responsibilities; second, the NAS Stage A equipment and the way sector controllers use it; and third, alternative ways to man a control sector.

1. En Route Control Procedures

Although each sector team is responsible for aircraft within its assigned airspace, air traffic control operations currently depend on a well-defined and highly structured system of intersector and interfacility control procedures that facilitate the orderly movement of aircraft through a multisector environment. Between adjoining sectors and facilities both formal letters of agreement and informal accords specify the usual aircraft altitudes, speeds, headings, and in-trail separations that should be established when jurisdictional control over aircraft is transferred from one sector team to another at their common boundary; these procedures reinforce an established system of preferential traffic routes.

The intersector agreements provide decision-making guidelines for sector control by defining the traffic flow strategies and mechanisms by which jurisdiction is delegated to individual sector teams without requiring excessive coordination between them. For example, a control team accepting aircraft at its sector boundary need not be concerned with how the preceding sector team controlled the aircraft, providing it is properly set up in accordance with the intersector procedural agreement. Sector decisions regarding which control techniques (for example, vectoring, altitude, or speed restrictions) should be used in structuring traffic for sector transit and exit are internal functions of each sector team. The sector teams are essentially autonomous decision-making units operating under the traffic organization requirements of the procedural agreements; supervisory, coordinating, and support personnel are not active in routine minute-by-minute issuance of sector control instructions.

The system of procedural agreements and preferential routes arranges each sector's traffic flow so that sector control becomes somewhat standardized, resulting in a fairly stable set of control techniques. However, flexibility in intersector traffic management can be introduced directly between adjacent sector teams or facilities; such coordination is often necessary as traffic situations or weather change. A sector team, for example, may request another sector team to adjust spacings between aircraft in order to coordinate aircraft sequences, or one facility may request another to constrain traffic overloading situations. Similarly, altitude and speed restrictions may be applied or removed as situations warrant such changes.

2. En Route Sector Control Operations

The NAS Stage A hardware and software systems capabilities include:

- Automatic flight data processing and forwarding.
- Automatic tracking displays with alphanumerics (including ground speed and Mode C, or pilot-reported, altitudes).
- Automatic and manual display filtering.
- Surveillance data mosaicking.
- Simplified clearance and coordination procedures.

These system capabilities support the sector controllers who provide separation assurance and traffic flow facilitation services to aircraft. Controllers maintain minute-by-minute surveillance of aircraft movements, make control decisions, transmit clearances and advisories to pilots, communicate with other controllers to coordinate their control actions, and manually maintain computerized and hard-copy paper data records describing control actions for each flight.

To perform these activities with support from the current NAS Stage A automation, sector controllers are equipped with air/ground (A/G) radio and interphone voice communications, a plan view display (PVD), a flight progress board, and computer data entry and display devices.

a. Air/Ground Communications

Control messages that are voice communicated to pilots by a sector controller over A/G radio include clearances (that is, assignments or approvals of specific routes, headings, altitudes, and speeds), and information describing proximate traffic, weather, navigation equipment operation, and so forth. Direct voice communication provides some flexibility by allowing a pilot to negotiate with a controller in the event an instruction cannot be readily followed; positive confirmation of instruction compliance is also transmitted by voice. Since most aircraft in a sector are on the same radio frequency, the A/G communication is on a "party line," with aircraft crews monitoring each other's instructions and responses.

b. Coordination Communications

Controllers voice communicate with each other by means of interphone or face to face. Interphone equipment allows intersector (including interfacility) voice communication. Any sector team is accessible by dial code, and communication between adjacent sector teams is initiated by push button. The interphone system mostly is used to advise sector teams of the details of irregular traffic organization and to negotiate adjustment when nonroutine control procedures are used. Deviations from the normal traffic pattern may be unusual flight plans or pilot requests for excursions because of weather or conflict avoidance maneuvers. Such traffic deviations generally are not problems, but they must be coordinated between sector teams to ensure that all control personnel are prepared to handle the traffic flow without any last-minute surprises.

Controllers of a sector team also coordinate with each other by means of direct (face-to-face) voice communications.

c. Plan View Display

The PVD is a cathode ray tube (CRT) that presents digitally-processed radar-derived symbolic and alphanumeric aircraft situation and flight data. A sector controller relies on continuous PVD surveillance as a base to mentally project flight trajectories and conduct conflict searches. His picture of current and future traffic situations includes a conceptual overlay of the standard control procedures (including minimum separation requirements) and preferential routes as well as a thorough knowledge of aircraft performance characteristics. The controller mentally compares his traffic projections against the traffic structuring guidelines specified by the control procedures in order to formulate control decisions.

A component of the NAS Stage A system digitizes primary and beacon radar data received at a remote radar site for transmission to the Central Computer Complex (CCC) located in each center. Each radar target is automatically tracked and correlated with flight plan and identification information. Aircraft track position symbols are displayed on the PVD, and alphanumeric flight information is presented in data blocks adjacent to the PVD position symbols. Also presented on the PVD are lists of the sector's departure, inbound, and holding aircraft; sector boundary and route maps, weather data, and emergency or special alert data.

The alphanumeric aircraft data block information aids the controller's awareness of current and planned traffic situations, becoming increasingly important as sector traffic levels rise. The data block presents aircraft flight identity, current altitude, and assigned altitude information that assist the controller to recall each aircraft's current and planned flight path. This information is particularly useful to a controller who must cope with dynamic traffic data. A controller can concentrate attention on traffic presented in one area of the PVD, while other data are automatically being updated without controller assistance. The identities of aircraft that will be entering a sector but that are not yet under the sector team's jurisdiction.

A digital data file on tracked aircraft is automatically maintained by the system, and the computer data processing permits selective line-projection displays of aircraft planned routes and current vectors. The controller retains responsibility for making and implementing decisions. Using PVD surveillance and his own mental calculations, the controller knows from moment to moment where each aircraft is, and where it is going.

d. Flight Progress Board

A sector controller's mental traffic picture-keeping process is also supported by the flight progress board. It contains paper flight progress strips that describe each aircraft's route, altitude and speed plans, beacon code assignment, and equipment. This basic information supplements the PVD data blocks by indicating flight plans and aircraft capabilities that must be known by the controller.

The flight progress board contains an active flight strip corresponding to each aircraft currently under the jurisdiction of the sector team and a "proposal" flight strip for each aircraft expected to enter the sector in the near future. Controllers are responsible for arranging all flight strips according to location (fix postings), time-sequencing them in a tabular format, and removing and storing used flight strips. The controllers maintain a handwritten record of traffic control activities (for example, altitude, speed, or heading revisions, intersector control jurisdiction transfers, and radio frequency changes) on each active strip. The controllers update the proposal strips according to messages received from other controllers or the CCC.

The flight strips currently also serve an important failure-mode function for surveillance. In the event of a complete failure in the radar data presentation capability, the flight strips are used (in conjunction with A/G position reports) by the sector team for on-line flight following. Manual sector operation requires an increase in the minimum separations allowable between aircraft.

A sector's paper flight strips are actually produced by a flight strip printer and manually delivered in individually loaded plastic holders to the sector controllers. The printer is driven by the CCC, which is receiving manually-input and radar-derived aircraft flight data. Flight strip printing is typically activated 15 minutes before the aircraft is expected to enter the sector.

e. Computer Data Entry and Display

In addition to maintaining the flight progress board, the sector controllers update flight plan data stored in the CCC and perform control system actions by using data entry devices and a CRT display referred to as the computer readout device (CRD). Each sector position is provided with CRD and data entry equipment; the latter includes an alphanumeric keyboard. In addition, the radar control position includes trackball and category/function controls.

Update messages entered into the CCC through the keyboard are simultaneously displayed on a CRD. These messages (for example, altitude revision) are records of traffic control instructions issued by a controller and are manually recorded on the flight progress strips. Controller A/G transmissions, therefore, often initiate a series of

manual activities by the controllers in order to keep the ATC system data current.

Maintaining both the flight progress board and CCC data records entails some duplication of effort because identical data are entered in both systems. However, these operations are required under current NAS Stage A operations. Updating the flight progress board data provides the sector team with a record of recent control clearances, whereas updating the CCC data base facilitates computer radar tracking, PVD data block presentation, and flight plan/flight strip distribution. Flight plan updates entered by one sector team, for example, are transmitted by the CCC for display on a CRD of another sector. Controllers of the latter sector must read the flight plan update displayed on the CRD, and manually copy (handwrite) the update onto a proposal flight strip. Where such flight plan updates occur frequently, considerable time is spent in revising paper flight strip data.

Intersector control messages that initiate and conform control jurisdiction transfers (handoffs) between adjacent sectors or point out traffic of interest are also input through the keyboard/trackball devices. Control transmissions initiated by one sector team force message symbols or data blocks onto the PVD of another team; in this way, handoffs are initiated and confirmed without oral communications. Both handoffs and pointouts are manually recorded on the flight progress strips.

PVD presentation controls are also located at the sector positions. These include range control and off-centering keys to reorient the overall radar display; mode keys to select or inhibit digitized radar altitude reporting and track data display alternatives; field select keys to adjust the informational content and positional orientation of the alphanumeric data blocks; and a radar history control to select or inhibit the display of aircraft trails. These devices are used by a sector controller to select the PVD presentation that best satisfies his needs.

3. Sector Manning Alternatives

The lead member of a NAS Stage A en route sector team is the radar (R) controller, who is responsible for minute-to-minute decision making (for separation assurance and traffic flow facilitation), voice communications, and data maintenance. He may be supported by a data (D) controller, or by a D controller and a tracker (T) controller.* During periods of light traffic, the R controller may man the sector alone and therefore perform all necessary activities. However, as traffic increases, the R controller's workload restricts his performance,

*The tracker position is termed the data/radar (D/R) position at the Los Angeles Center.

necessitating the allocation of some operational activities to one or both of the other team members.

The sector team operation is supported by an assistant (A) controller, who reviews, collects, and delivers flight strips to each sector team. One A controller typically services two sectors.

As result of alternative ways by which controller positions may be activated, three sector team manning strategies are of interest: a 1.5-man team (R controller and one-half the services of an A controller); a 2.5-man team (R and D controllers and one-half the services of an A controller); and a 3.5-man team (R, D, and T controllers and one-half the services of an A controller). The 2.5-man team is currently the most often used manning of sectors at the Los Angeles and Atlanta Centers.

a. <u>1.5-Man Team</u>

The R controller performs all the sector control operations necessary for separation assurance and traffic flow facilitation. These operations include surveillance, A/G communications, computer data entry and display, flight strip processing, interphone communications, face-to-face direct voice coordination, and related decision making. The A controller delivers flight strips to the sector.

Since 1-man sector team operations were not in use at either the Los Angeles or Atlanta Centers (at least during our field data collection exercises), we infer that the broad range of decision making and manual activity make such operation undesirable, even in times of moderate traffic. The most likely use of 1-man sectors at a center would be during midnight shift operations where traffic activity is low. However, during such traffic circumstances, combining sectors with 2.5-man operation may be preferred.

b. <u>2.5-Man Team</u>

The R controller retains full responsibility for surveillance, A/G voice communications, and related decision making, but shares with the D controller the responsibility for computer data entry and display actions, flight strip processing, and interphone voice coordination. (Both controllers coordinate with each other by means of face-to-face direct voice communications.) The sharing of control responsibilities among sector team positions is somewhat fluid at lower traffic levels, but it becomes more stable as activity is intensified to process more traffic. This stabilization is due to the workload efficiencies gained by distributing control activities and due to the operating requirements and arrangement of the sector equipment.

The R controller who is making decisions and issuing control instructions must concentrate on surveillance and A/G communication

activities; but he also devotes attention to various activities concerning computer data processing and flight strip maintenance. The activities are highly interactive in that one action (for example, altitude instruction) requires a reaction (for example, CCC and flight strip update). Still, the relative importance of the various tasks is readily discernible; for safety, traffic control decision making cannot be delayed. It is important that the R controller be able to shift his attention from one traffic situation to another with minimum delay and distraction. Therefore, as traffic peaks intensify, the R controller gives as much of the less time-critical manual work to the D controller as he can. During peak traffic conditions, the R controller devotes most of his time to surveillance, A/G communications, current flight strip updating, and PVD adjustment work, while the D controller absorbs the remaining manual CCC data base and flight strip maintenance tasks as well as the bulk of the interphone coordination with other sector controllers. The R controller may perform some flight data processing work (for example, control jurisdiction handoff initiation and acceptance, flight plan updating) on a time-available basis while the D controller may assist the R controller in updating active strips as time is available. (It is of interest to note that, since the D controller is performing the intersector coordination, he must be familiar with standard control procedures and knowledgeable of his sector's current and planned traffic structures.)

c. 3.5-Man Team

The R controller retains full responsibility for surveillance, A/G voice communications, and related decision making, but off-loads the bulk of the remaining manual activities and coordination communications to the T and D controllers. The T controller works closely with the R controller by entering computer data in reaction to R controller instructions to pilots, and assisting in updating active flight strips. The D controller performs much of the interphone communications and the less traffic-reactive flight data processing manual operations (for example, flight plan updating) and manual flight strip processing (for example, sequencing and removal). We noted at the Atlanta Center that the T controller is physically located between two adjacent sector consoles so that he can use both sectors' keyboards to manually initiate and accept handoffs between the two sectors. However, in this so-called "half-man" operation, his primary function during busy periods is to directly support only one of the two R controllers, thus effectively being integrated into the control operations of one sector team.

B. ETABS Operations

The ETABS is to provide an electronic alphanumeric display of flight data and a quick-action touch-entry data input device. This equipment would replace the paper flight strips and flight progress boards, and some of the keyboard data entry devices at sector positions. The ETABS display data will be updated automatically by the CCC and accessible by

the sector team touch-entry device. ETABS is designed to eliminate current NAS Stage A system requirements to simultaneously perform redundant computer flight data processing and flight strip processing operations. ETABS is also designed to simplify computer entry manipulations for data updates, handoffs, and pointouts.

1. Sector Control Effects

ETABS affects sector control operations by introducing more efficient means of processing data by automating current manual methods, but would not affect surveillance, decision making (for separation assurance and traffic flow facilitation), and A/G voice communication requirements as currently conducted. Use of ETABS would affect control work by eliminating certain manual tasks and altering other tasks, which jointly would affect sector team manning requirements.

Clearly, with the removal of the flight progress board, all attendant manual activities associated with flight strip processing would be eliminated by ETABS. Some current activities (for example, flight plans for unexpected aircraft "pop-ups") could not be eliminated. Despite this requirement, important reductions in manual workload requirements are achievable by ETABS. For example, the current task of hand-copying flight plan updates from the CRD onto proposal flight strips would be performed automatically by ETABS. In addition, ETABS would provide an alert feature to attract the attention of the controller when there are flight plan changes or updates. Sequencing, arranging, and removing of flight data would be automatic. While these tasks may not seem intricate, they are now being performed manually and therefore consume controllers' time. Elimination of such mechanical tasks would enable the controllers to spend more time with surveillance, decision making, and communication functions.

Controller work time required for handoffs and pointouts could be reduced by ETABS. For example, automatic exchanges of flight plan data between sector tabular displays would circumvent the need for the interphone communications that are currently needed to transmit such data as part of pointouts. The electronic display of these data could be effected more quickly than oral voice transmissions. We expect that ETABS would provide means for checking on the completion of important control actions (for example, issuance of A/G radio frequency change instructions), and to warn controllers of the need to carry out such functions if they have been overlooked. These kinds of automatic checks would facilitate fully automatic handoff operations.

Earlier reports[1-3] have discussed in greater detail the nuances of the ETABS effect on sector control operations, using the Los Angeles and Atlanta Centers as case study subjects. These examinations, which included analysis of controller workload requirements and traffic handling capabilities, addressed the distribution of work among various sector team positions. The studies found that, with the elimination of flight

strip processing activities and related data processing efficiencies, little gain in traffic handling capability could be achieved by using both a D and T controller to support the R controller, rather than by using only the D controller. In effect, the D controller with ETABS could perform the work currently assigned to the T and D controllers (in the 3.5-man team) with the current NAS Stage A system. Furthermore, the elimination of flight strips and the reduction of some computer data entry requirements would also alleviate the R controller's work and enable him to increase his overall traffic handling capabilities.

The automatic transfer of flight data and the elimination of paper flight strips would mean that the A position would no longer be necessary, provided that the automated system operated with a high degree of reliability. The advent of advanced microprocessing technology is expected to provide continuity of tabular display operation through redundant software and hardware equipment. Otherwise, if such fault tolerance are not provided, an important benefit of automated data handling could not be realized, because flight strip printers and A controllers would probably be needed as backups.

2. Controller Team Manning Effects

As a result of the above observations concerning ETABS operations, two sector team manning regimes are relevant: a 1-man team (R controller); and a 2-man team (R and D controllers).

a. 1-Man Team

The R controller performs all the controller operations necessary for separation assurance and traffic flow facilitation as described previously for the current NAS Stage A 1.5-man team (except that flight strip delivery and processing are no longer performed). Computer data entry operations are performed primarily by using touch-entry devices rather than keyboards.

Also, as in the case of the NAS Stage A 1.5-man team, the broad range of decision making and manual activities is expected to make the ETABS 1-man team difficult to implement except in light traffic situations.

b. 2-Man Team

The R controller retains full responsibility for surveillance, A/G voice communications, and related decision making, while the D controller performs computer data entry, display operations, and interphone voice communications. This division of responsibility is analagous to that described for the current NAS Stage A 2.5-man team.

C. Current NAS Stage A versus ETABS Operations

To summarize the preceding discussions of this section, ETABS affects current NAS Stage A sector operations by:

- Reducing to some degree the R controller task work requirements
- Eliminating the need for A controllers
- Eliminating the need for T controllers.

The first item above would increase sector capacity to the extent by which the R controller could actually experience workload reductions because of ETABS. Previous studies have found[1,2] that the expected ability of ETABS to increase current sector capacity varies from sector to sector, and may not be particularly significant in a sector where an R controller's data processing activity is currently a minor portion of his overall workload.

The second item above at first glance would appear to be important in terms of productivity, because the A position need not be manned. But staffing reductions may not necessarily accrue because the developmental controllers normally manning the A positions need to be hired and trained regardless of A-position requirements. To clarify the effect on staffing due to A-position elimination, this situation was modeled in detail, as described subsequently in this report.

The third item above is extremely significant in terms of manpower reductions because this item asserts that two controllers (that is, R and D controllers) with ETABS can handle the traffic worked by 3.5 controllers with the current NAS Stage A. Discounting for the moment the significance of eliminating the A position (the one-half man), a D controller with ETABS should negate the need for including a T controller in a sector team. The T controller in an ETABS environment could not measurably off-load additional work from the R controller that has not already been assigned to the D controller and ETABS. As a result, the T controller could not increase sector traffic capacity significantly above the capacity gains attributed to ETABS. In effect, ETABS implementation replaces the T controllers who otherwise would have been activated at higher traffic levels in the current Stage A environment.

III CONTROLLER STAFFING REQUIREMENTS

This section describes the methodology for estimating controller minimum staffing requirements for the current NAS Stage A en route (System 1) and the proposed NAS Stage A with ETABS (System 2) operations. The methodology determines the minimum number of controllers required to operate the 20 domestic centers for each year from FY 1977 through 1999. Specifically, the annual minimum manpower needed to staff R, D, T, and A positions, exclusive of supervisory, support, and maintenance personnel, is studied. These minimum staffing requirements do not include advance recruitment effects, which would cause the actual on-board controller staff to be greater than the minimum requirements. Advance recruitment as well as additional air traffic service and airway facilities service staffing are addressed in the next section of the report.

The remainder of this section includes: first, an introductory review of the methodology for estimating controller requirements; second, an analysis of ETABS effects on sector manning; third, an analysis of ETABS effects on multisector manning; fourth, an analysis of 1976 baseline staffing requirements; and fifth, a review of traffic forecasts.

A. Controller Requirements Estimating Methodology

The basic estimation procedure is to use the results of the two previous case studies[1,2] of staffing requirements for the Los Angeles and Atlanta Centers to determine national staffing needs. As part of each of the case studies, System 1 and System 2 operations were analyzed, and staffing growth trends were related to traffic growth trends. For the purpose of this research, the System 1 and System 2 staffing-versus-traffic relationships obtained for the two case study sites will be updated. The arithmetic average of the resulting two-site staffing growth factors will be used to estimate national staffing factors. Staffing requirement factors will be developed separately for System 1 and System 2 operations. These national growth factors will be applied to 1976 baseline requirements in order to estimate national annual staffing requirements corresponding to national traffic growth projections. The results will enable comparisons between System 1 staffing requirements and those of System 2.

Each case study includes an analysis of individual sector operations in which sector control team traffic handling capabilities are related to sector controller workload limitations. Workload models describing controller task activities under System 1 operations are constructed using observed data collected on-site by SRI. Workload models corresponding to System 2 are made by judgmentally adjusting controller task

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parameters to reflect ETABS operations. The workload modeling approach, referred to as the Relative Capacity Estimating Process (RECEP), enables us to estimate sector traffic capacities corresponding to alternative manning strategies, and to examine the impact of ETABS on manning and capacity relationships for individual sectors.

In order to examine manning requirements on a multisector basis, the RECEP sector capacity results are used as input into an Air Traffic Flow (ATF) network simulation. ATF is used as part of each case study to define relationships between manning, capacity, and delay during the 8-hour day shift of the busy day (37th busiest) for a selected multi-sector region. The results obtained enable one to estimate the number of R, D, T, and A positions required to maintain the FY 1976 baseline level of delay for various levels of postulated traffic growth. These multisector manning requirements, which consider alternative sector manning strategies and sector reconfigurations (that is, sector splits), are developed for both System 1 and System 2 operations.

The traffic-dependent multisector R, D, T, and A position requirements are compared against 1976 baseline manning and traffic situations in order to develop manning factors as a function of traffic. These latter factors are expanded into facility-wide annual staffing factors by accounting for relief and annual leave needs, and midnight, day, and evening facility-wide sector manning patterns. The resulting staffing factors developed for each case study are averaged to obtain national staffing requirement factors for System 1 and System 2 operations. For use in our subsequent analysis of advance recruitment, the national staffing requirement factors distinguish R, D, T, and A position qualifications.

The following paragraphs further describe and demonstrate the controller staffing requirement estimation methodology. Additional details are contained in the appendixes to this report and in the case study reports.[1,2]

B. ETABS Effects on Individual Sector Manning

The distribution of workload among positions within a sector is responsive to the time-varying traffic processing requirements. As the number of aircraft in a sector increases, the corresponding increase in the frequency of R controller decision-making actions generates more manual and verbal activity distributed among the appropriate positions. Each controller's ability to handle his workload is limited by the time available. SRI's RECEP assessment of traffic constraints associated with a controller's decision-making, manual, and verbal activities produces a workload value that corresponds to the traffic capacity of a sector team.

RECEP models include mathematical representations that relate controller work to sector-specific parameters describing the aircraft flow

rates and speeds along each route, the separation minima, the intersection and merging angles between the routes, the numbers of intersections and merges, the length of routes, and the number of flight levels at which conflicts can occur. The mathematical formulations are structured to reflect specific sector and traffic characteristics affecting conflict events. For example, the blocking of more than one altitude by a transitioning aircraft, the application of in-trail separation rules to aircraft on a single route regardless of altitude separation, and the mixing of aircraft with different speed capabilities are readily modeled.

The RECEP model structure represents controller team task activities according to three categories:

- Routine workload
- Surveillance workload
- Potential conflict processing workload.

Routine work tasks include A/G voice communications, manual data entry, display operations, flight strip data processing, intersector interphone voice communications, and intrasector direct (face-to-face) voice communications. Surveillance work is visual observation of radar-derived aircraft situation data on a PVD. Conflict processing work includes potential conflict recognition, assessment, and resolution decision making and A/G voice communications.

Using data observations and mathematical relationships, the routine, surveillance, and potential conflict processing work is broken down in RECEP by describing the component

- Task times
- Task frequencies
- Task assignments (team work distribution).

Given as input the minimum task performance times (seconds), task frequencies (events per aircraft), and the allocation of work among sector team members, RECEP estimates the aggregate work time (man-minutes of work per hour) experienced by the team or by individual team members. The routine, surveillance, and conflict processing workload requirements are formulated as functions of traffic flow rate and sector transit time. The aggregate work times resulting from various rates of traffic flow through a sector are compared with an empirically calibrated workload limit* to obtain sector team capacity estimates (aircraft per hour).

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*The calibrated workload limit of the R controller, for example, is 48 man-minutes of work per hour, which is 80 percent of the 60 man-minutes available.

1. NAS Stage A Sector Modeling

The RECEP models of NAS Stage A baseline system sector team operations are constructed using field observations and related data collections at the Los Angeles and Atlanta Centers.[1,2] These models represent the controller workload requirements (that is, routine, surveillance, and conflict processing) associated with the baseline manning characteristics of each sector under analysis. Therefore, these models describe sector team traffic capacities under baseline operating conditions concerning sector configurations, route geometry, and procedural rules.

To allow for baseline system staffing increases in response to future traffic increases, the workload structures of the current baseline system RECEP models are adjusted to represent realistic sector team manning alternatives (for example, expand from 2.5-man to 3.5-man teams) and resectorizations (for example, split one sector into two sectors and provide additional controllers).

Because the RECEP sector capacity estimates will be used in ATF analyses of day-shift, busy-day operations, only the 2.5-man and 3.5-man sector team workload structures are modeled. The 1.5-man team operations were not observed in use at the two case study sites during the day shift. The 2.5-man team models are based entirely on formal on-site data collection efforts, while the 3.5-man team models are based in part on informal on-site observations (made only at the Atlanta Center where the T position is manned on occasion) and on controller descriptions of 3.5-man team work responsibilities. The RECEP models describe the specific set of task times, task frequencies, and task work assignments that vary from sector to sector depending on whether 2.5-man or 3.5-man teams are in operation.

Modeling sector splits is less refined because route restructuring effects on sector workload requirements are not known and must be judgmentally determined. Therefore, a rough approximation is obtained of the workload and capacity relationships associated with the distribution of workload among the sectors formed by splitting. A first-order sector splitting model developed by SRI[3] takes into consideration the reallocation of conflict processing work and the additional routine work introduced by new sector boundaries. This model was used to study Los Angeles Center sector splits. In subsequent productivity analysis work for the Atlanta Center, we have used the Los Angeles Center results as analogies from which we estimated the percentage increase in traffic capacities resulting from splitting sectors.

The RECEP models of current NAS Stage A operations, alternative sector manning strategies, and resectorizations obtain traffic capacity estimates for each baseline sector for each operating configuration. This set of RECEP models therefore describes the sector capacity effects resulting from sector personnel changes for the baseline system.

2. ETABS Sector Modeling

The same procedure is followed as that for the baseline system to define RECEP models for ETABS sector operations postulated under alternative manning and sectorization options. First, RECEP workload requirements are constructed for each sector using a sector manning strategy analogous to the current one. The workload requirements are constructed by adjusting the baseline system's routine tasks to conform to an ETAB sector's operating characteristics. These adjustments encode the assumptions made as to how ETABS would be implemented in an operational control environment. Then, as described for the baseline case, realistic sector manning strategies and resectorization alternatives are modeled. The resulting RECEP models obtain sector capacities corresponding to the alternative sector staffing levels for the ETABS system under evaluation.

In accordance with the descriptions of System 1 and System 2 sector team operations (given previously in Sections II-A and II-B of this report), only the routine workload components of the RECEP models need be adjusted to represent ETABS operations. These adjustments assume that surveillance and potential conflict processing work tasks will not change with ETABS implementation, but that the flight strip processing, computer data entry and display, and controller coordination (interphone and face-to-face direct voice) task components of routine work will be affected. The routine workload parameters are changed by judgmentally adjusting the minimum times and frequencies of those tasks that we expect will be altered by ETABS. For example, the modeling adjustment assumes that flight strip processing tasks will be eliminated completely by ETABS, and no flight strip processing workload will accrue in our RECEP models for ETABS. Similarly, the modeling adjustment made allowances for additional data entry and display actions required to replace some flight strip tasks, but these additional tasks may be counterbalanced by other changes to data entry requirements (for example, removal of redundant data recording operations).

The modeling of System 2 sector splits is as described for System 1 sectors; that is, proportionate adjustments to sector traffic capacities are based on first-order workload modeling of analogous sector reconfigurations. Only the 2-man ETABS sector team operation will be modeled, because 1-man operations would not be feasible during the moderate to heavy traffic situations of the day-shift, busy-day operations.

3. Demonstration of Sector Modeling Results

The sector traffic capacities of interest are those that correspond to alternative

- Sector manning strategies
- Sectorization configurations (sector splits).

a. <u>Sector Manning</u>

The sector manning strategies of interest are as follows:

- System 1A--NAS Stage A, 2.5-man team
  - R Controller
  - D Controller
  - 1/2 A Controller
- System 1B--NAS Stage A, 3.5-man team
  - R Controller
  - D Controller
  - T Controller
  - 1/2 A Controller
- System 2--ETABS, 2-man team
  - R Controller
  - D Controller.

The application of RECEP is demonstrated using one sector analyzed as part of the Atlanta Center (ZTL) case study. Sector 41 (Norcross) is an arrival sector handling mostly descending aircraft transitioning from higher altitudes to the Atlanta Terminal area. The routine workload analysis for the R controller for Systems 1A, 1B, and 2 are summarized in Table 3. Derivation of the workload values are described in Ref. 2, parts of which are excerpted into Appendix A of this report. Descriptions of the corresponding team workload models are available in Ref. 2. To simplify this discussion, we will address only the R controller workload, which is analogous to team workload modeling.

With reference to Table 3, the R controller's A/G communication tasks are assumed to be held constant, regardless of manning strategy or ETABS implementation. However, with the change from 2.5-man to 3.5-man team operations, other portions of the R controller's work are assumed to be off-loaded to the T and D controllers. Thus, reductions occur in the R controller's work time (in terms of man-seconds per aircraft) required for computer data entry and display, and for flight strip processing tasks. These reductions occur because the T controller works closely with the R controller to maintain data records and relieves the R controller workload. A 10 percent reduction in the Sector 41 R controller's total routine work is achieved by switching from System 1A (the current NAS Stage A 2.5-man team) to 1B (the current NAS Stage A 3.5-man team).

With the implementation of ETABS, all flight strip processing work is eliminated, while some additional computer data entry and display tasks are assigned to the D controller. The D controller is

Table 3

ATLANTA CENTER SECTOR 41: R CONTROLLER ROUTINE WORK

System	Sector Manning (number of men)	R Controller Routine Workload (man-seconds/aircraft)				
		A/G Communications	Computer Data Entry and Display	Flight Strip	Sector Communications	Total
1A, NAS Stage A	2.5	35.6	4.3	12.9	5.7	58.5
1B, NAS Stage A	3.5	35.6	1.3	10.0	5.7	52.6
2, ETABS	2	35.6	0.3	0	5.0	40.9

capable of assuming these tasks because ETABS automatically performs certain time-consuming tasks that were manual under System 1. Also, reductions in certain face-to-face direct voice communications associated with pointouts reduce the R controller's time spent in sector coordination. A 22-percent reduction in the Sector 41 R controller's total routine work is brought about by switching from System 1B (the NAS Stage A 2.5-man team) to System 2 (the ETABS 2-man-team).

The work task structure postulated in the RECEP models for ETABS is based on somewhat conservative assumptions so as to prevent biasing the results in favor of ETABS. For example, certain data entry events were assumed to require 3 man-seconds each of manual work, which is similar to the data entry times using the current NAS Stage A keyboard apparatus. However, it is likely that with the use of quick action, touch entry devices, data entry with ETABS might require only 2 man-seconds of manual work per event.

In regard to sector traffic capacity analysis, the RECEP estimates of Sector 41's traffic capacities for systems 1A, 1B, and 2 are summarized in Table 4. In the case of Sector 41, the R controller's workload--rather than that of the sector team's--was found to be the constraining determinant of traffic capacity for the three systems. A capacity gain of 7 percent is attributed to System 1B relative to 1A, and a 6 percent gain is attributed to System 2 relative to 1B.

Table 4

ATLANTA CENTER SECTOR 41: CAPACITY
AND PRODUCTIVITY COMPARISON

	1A NAS Stage A	1B NAS Stage A	2 ETABS
Sector manning (number of men)	2.5	3.5	2
Capacity (aircraft per hour)	30	32	34
Productivity (aircraft per man)	12	9	17

While these capacity gains may not be dramatically large, a more significant effect is achieved in terms of the number of aircraft handled per man. If we examine the aircraft handled per man at capacity, as shown in Table 4, we see that a 25 percent loss in productivity is associated with System 1B relative to 1A. In this case, the capacity increase of the 3.5-man team versus the 2.5-man team is more than compensated for by the increased manning. However, the capacity gain associated

with ETABS, together with its concurrent reduced sector manning requirements, obtains a 90 percent productivity gain relative to the current 3.5-man NAS Stage A operation, or a 42 percent productivity gain relative to the current 2.5-man NAS Stage A operation.

The productivity gains associated with ETABS will be the basis for benefits attributable to System 2. Recall these gains are based on the assumption that 2 men with ETABS can out-perform or at least match the capabilities of 3.5 men with the current NAS Stage A. However, some caution is warranted in this analysis since developmental controllers currently man the A position, and such controllers would need to be hired and trained regardless of whether ETABS eliminates this position. (The analysis of developmental requirements is included as part of the advance recruitment modeling in the next section of this report.) While this analysis might show no significant staffing reductions resulting from A-position elimination, very important ETABS staffing benefits are attributable to the elimination of the T controller.

The capacity and productivity results shown for Sector 41 are representative of the RECEP analysis technique. These results are not necessarily the same as would be obtained for other sectors. The RECEP models are designed to represent the unique operational characteristics of different sectors.

b. Resectorization

This study assumes, as is the current practice, that sector design reconfigurations will be required as traffic increases (regardless of which system alternative is under consideration). Reconfiguration entails modifying the sector boundary, route, and procedural rule structure of a facility, and normally requires sector splitting and airspace reallocation to create new sectors. This resectorization adds new sectors (and the controllers needed) so as to increase capacity and thereby reduce delays as traffic increases.

The sector splitting approach for defining sectorization alternatives is based on the one used during the Los Angeles Center case study[1] in which a sector split model* was applied to roughly estimate capacities resulting from reconfigurations of a low-altitude arrival and a high-altitude en route-transition sector. The analysis estimated that splitting the low sector into two sectors would increase the capacity of the original sector airspace by 40%, and splitting the high sector would increase its airspace capacity by 80%. Using these results for Los Angeles Center sectors, analogous reconfigurations of the Atlanta

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*The sector split model accounts for additional control work induced by new sector boundaries. Handoff, intersector coordination, pointouts, and some traffic structuring work are affected.[3]

Center were judged to increase the airspace capacity of arrival Sector 41 by 40 percent, for systems 1A, 1B, or 2. Other sectors studied in this manner were judged to be capable of experiencing capacity increases of 20 to 80 percent as a result of splitting. Each sector split assumes that the manning required to handle traffic through the original sector airspace would double.

This judgmental approach to modeling sectorization is used because of the uncertainty in predicting future reconfiguration implementations.

C. ETABS Effects on Multisector Manning

The computerized ATF network simulation model enables one to assess the capacity and productivity relationships for selected multisector operations. Given as input data the sectorization structure, route network design, aircraft routing characteristics, and the traffic capacity corresponding to specific manning strategies for each sector, the ATF simulation model loads traffic onto the route network and processes the traffic from sector to sector until capacity overload becomes imminent. ATF then delays aircraft along routes upstream of the congested sectors to prevent overloading. This process propagates delays through the sectors to the study area boundaries. ATF traces the propagation of traffic congestion and delays through the route network over time and calculates aircraft average delay statistics.

ATF is used to estimate the aircraft delay experienced during the busy-day day shift (8 hours) in a specific operational environment for a range of traffic-loading projections. The multisector environment is defined by specifying the route structure and control operation, NAS Stage A systems 1A or 1B or ETABS system 2. The control operation is represented by the RECEP-based sector capacities determined for the particular sector manning strategy and sector split configuration under study. Recalling the manning strategy and sectorization configuration determine the multisector manning level for the operation being modeled. The ATF delay therefore makes possible an assessment of the capability of alternative manning levels to handle increasing levels of traffic.

For our purpose of comparing system 1 and system 2 operations, manning and traffic levels corresponding to a common level of service will be determined. This common level of service is assumed to be the average aircraft delay experienced during 1976 baseline operations. In effect, the number of R, D, T, and A positions required to maintain baseline delay as traffic increases will be estimated for system 1 and system 2. That is, the additional manning and resectorization needed to constrain delay will be modeled. As will be shown, alterations to this manning estimation procedure will be made in those cases where additional manpower can no longer be assigned to effectively limit delay at higher traffic projection levels.

The application of ATF is illustrated by using the 9-sector study area of the Atlanta Center shown in part in Figure 2.

1. Multisector Model Structure

The Atlanta Center airspace for the 1976 base period includes 41 sectors, of which the nine sectors under study control primarily airline arrival, departure, and overflying traffic north of the Atlanta airport.

The primary arrival and departure air traffic routings within the Atlanta Center are configured in a radial pattern (four arrival and four departure corridors) with the Atlanta airport as the focus. The study area being modeled by ATF includes the two arrival corridors from the northeast and northwest and the northbound departure corridor. Portions of the route network are included in Figure 2, but ATF actually models a more complex system of route segments through the three-dimensional airspace.

a. Sector Capacity Estimates

Systems 1A, 1B, and 2 are differentiated in ATF by using the RECEP-derived *sector capacities* appropriate to each system. The ATF model constrains traffic flow, by imposing delays, to ensure that traffic flow through each sector at some instant in time does not exceed that sector's predetermined capacity. The representative sector capacities for each system are shown in Table 5 for the 1976 sectorization configuration. These capacities were obtained as part of the Atlanta Center case study.[2]

To analyze sector splitting, ATF is used to simulate three postulated sector configurations for the multisector area:

- Configuration 1: the current 9-sector arrangement (Figure 2).
- Configuration 2: 13 sectors (current 9 sectors, with Sectors 39, 40, 41, and 42 each split into two).
- Configuration 3: 18 sectors (original 9 sectors each split into two).

Reconfiguration is estimated to increase the airspace capacities as follows: the airspace capacity of departure Sector 38 by 40 percent (which is the same as the capacity of arrival Sector 41); the capacities of transition Sectors 37, 39, 42, and 43 by 60 percent; and those of high, en route Sectors 36 and 44 by 80 percent. The capacity of arrival Sector 40 is estimated to increase by 20 percent (rather than 40 percent) because of airspace limitations. These relationships are used in the ATF model to approximate the sector airspace capacities associated with the postulated sector splits of configurations 2 and 3.

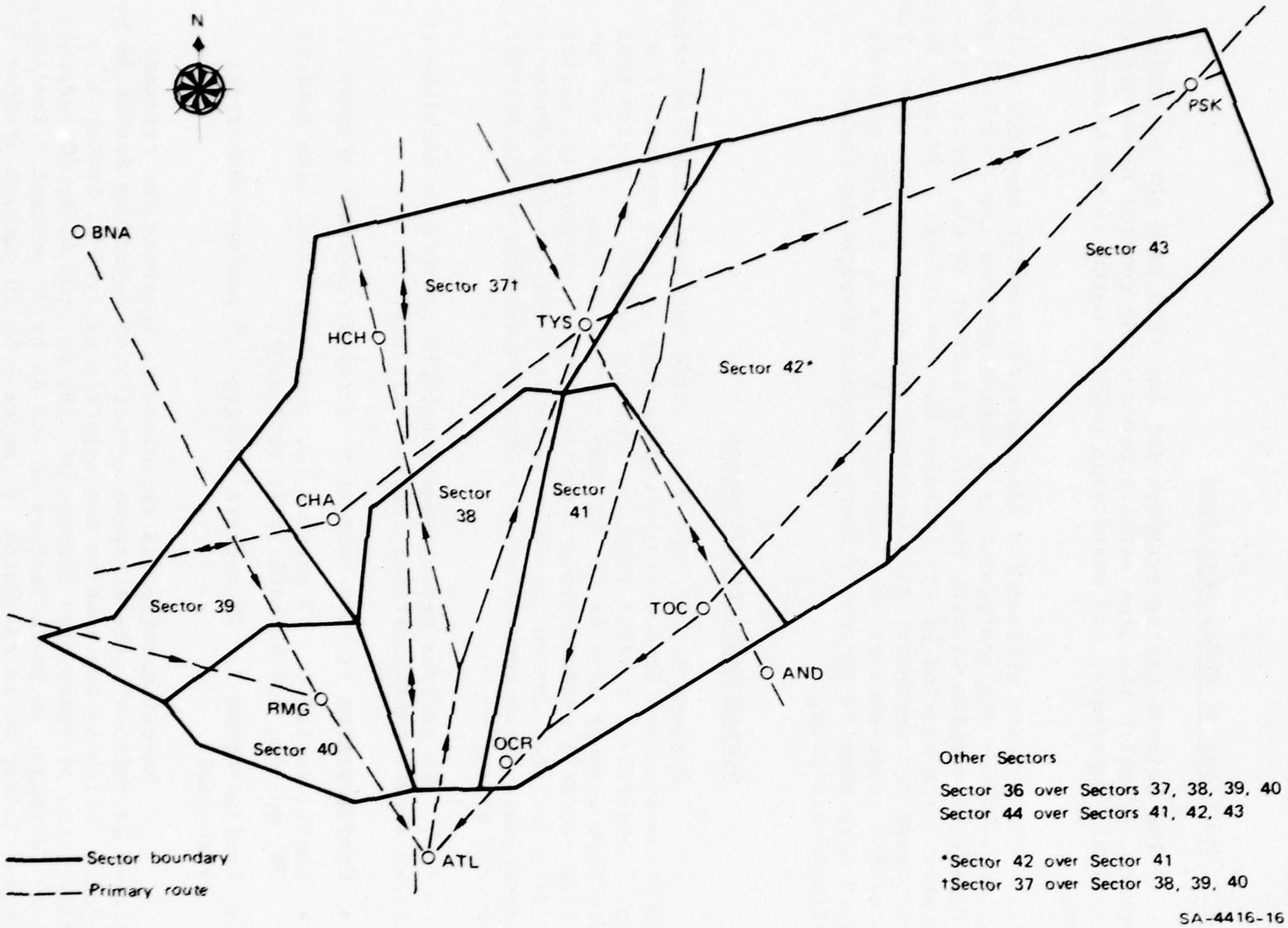

FIGURE 2 ATLANTA CENTER MULTISECTOR STUDY AREA

Table 5

ESTIMATED SECTOR TRAFFIC CAPACITIES: ATLANTA CENTER, CONFIGURATION 1 (9 SECTORS)

Sector Number	Traffic Capacity (aircraft per hour)		
	1A NAS Stage A (2.5 men/sector)	1B NAS Stage A (3.5 men/sector)	2 ETABS (2 men/sector)
36	42	44	47
37	38	42	45
38	50	55	66
39	45	50	55
40	33	35	40
41	30	32	34
42	37	40	43
43	42	45	49
44	40	43	45

b. Traffic Demand

Traffic demand patterns modeled by ATF are based on Atlanta Center flight strip records for a single day shift during December 1975 (when the traffic volume matched that reported for the FY 1976 busy day*). These data enabled a reconstruction of the routes flown by approximate time of day for the 486 aircraft (10 percent military) entering the study area during the 8-hour study period.

The exact arrival times at the study area boundary were not known; so, for modeling, the arrivals were assumed to be randomly distributed over successive 20-minute periods. For parametric analysis, this demand was scaled proportionately to provide traffic data at higher demand levels. Scaling was based on successive 10-percent increments of civil traffic; the number of military aircraft was not increased.

The scaling process used during the Atlanta Center case study to project increased traffic demand assumed that the current traffic peaking phenomenon would characterize future demand. Therefore,

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*The sampled traffic level was found to be roughly comparable to the FY 1975 busy-day traffic reported for the 9 sectors. A check of the FY 1976 busy-day traffic reported for the Atlanta Center found that no significant traffic increase had occurred. (An increase of less than one percent in day-shift aircraft handled is indicated.)

traffic was scaled into successive 20-minute periods in direct proportion to the current distribution of traffic. While such a "peaked" traffic profile might occur, this demand pattern represents one possible outcome. Another outcome could be a "smoothed" traffic profile in which local traffic peaks are constrained by voluntary scheduling or by regulatory practices. Such smoothing would redistribute traffic demand over the 8-hour study period (by washing out local peaks and filling in traffic demand valleys), but would not reduce the total traffic demand during the 8 hours.

In regard to ATF delay analysis, the peaked traffic demand would generate greater aircraft delay than would the smoothed traffic at the identical total 8-hour demand level. Therefore, as traffic projection increases are modeled, lower manning levels would be needed to constrain delay for the smoothed traffic than for the peaked traffic scaling. As a result, the smoothed traffic scaling would enable the existing NAS Stage A (system 1) to constrain delays further into the future than would the peaked traffic scaling. In the interest of conducting a conservative analysis of ETABS (system 2) impacts, the smoothed traffic scaling is used as the base case for demonstrating controller manning requirements. The effect of peaked traffic scaling is assessed as part of a sensitivity analysis in Section VI of this report.

2. ATF Model Results

a. Current Operations

The ATF estimate of the baseline level of delay is obtained by modeling the 1976 manning and sectorization situation for the Atlanta Center study area. These operations during the day shift are a mixture of 2.5-man (system 1A) and 3.5-man (system 1B) sector manning strategies in which one T controller supports, as needed, either the Sector 42 or Sector 44 R and D controller team, while another T controller supports either the Sector 36 or Sector 37 team. Therefore, during the day shift, 9 R positions, 11 D and T positions, and 4.5 A positions are manned, resulting in a total of 24.5 positions, as shown in Table 6. In regard to the one-half A position, the controller is also delivering flight strips to a sector not included in the study area. This assignment is possible because the study area includes positions of more than one formal area of specialty. The "extra" one-half A position is assumed to be servicing two sectors, both of which are in a single area of specialty, but only one of which is the study area.

ATF modeling for the baseline 9-sector configuration and manning under the baseline traffic loading of 486 aircraft per 8-hour shift resulted in an average delay of 0.03 minutes per aircraft. This ATF-determined delay level represents the common level of service at which alternative systems operations will be compared. The multisector traffic capacity is defined to be the area traffic loading that generates in the ATF model an average aircraft delay of 0.03 minutes over the 8-hour shift.

Table 6

BASELINE OPERATION: ATLANTA CENTER
(NAS Stage A--1A and 1B)

Number of Sectors	Controller Manning (number of persons)				Traffic Loading (number of aircraft per 8-hour shift)
	R	D and T	A	Total	
9	9	11	4.5	24.5	486
Note: ATF delay = 0.03 minutes/aircraft per day shift.					

b. Alternative Systems Operations

ATF is used to separately model systems 1A, 1B, and 2 for increasing levels of projected day shift traffic. Delay results for each system corresponding to the smoothed traffic scaling are shown in Figures 3, 4, and 5 for the 9-, 13-, and 18-sector configurations. The baseline level of delay is shown as the horizontal curve on each figure.

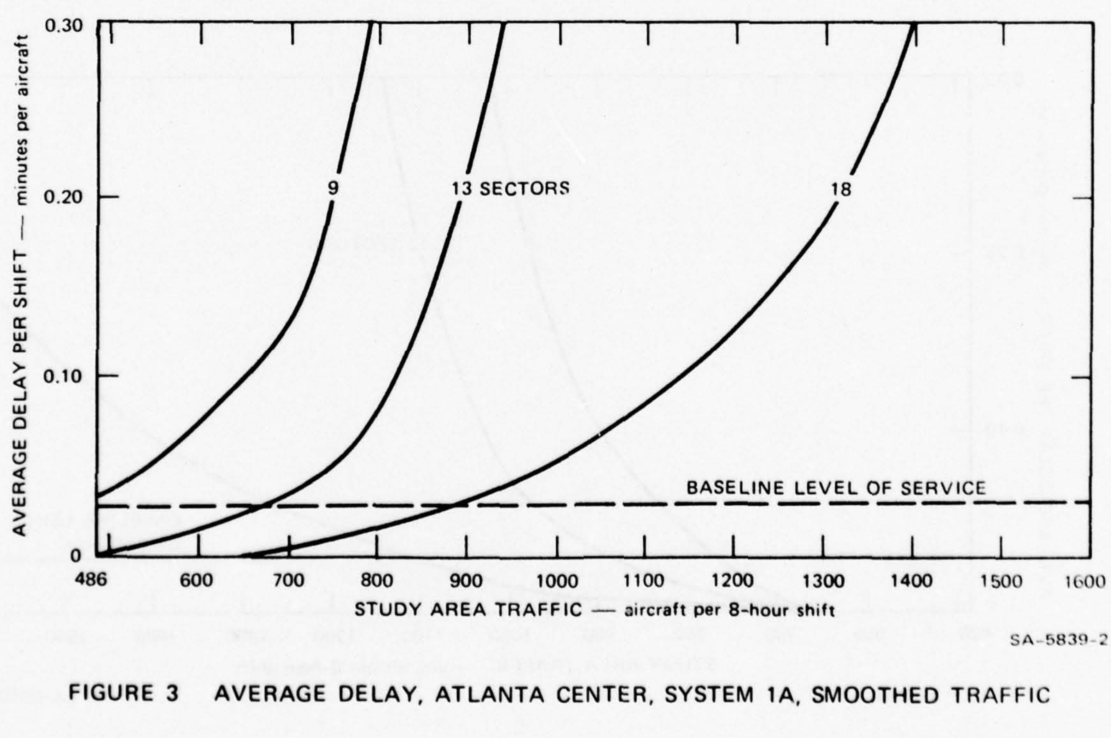

FIGURE 3 AVERAGE DELAY, ATLANTA CENTER, SYSTEM 1A, SMOOTHED TRAFFIC

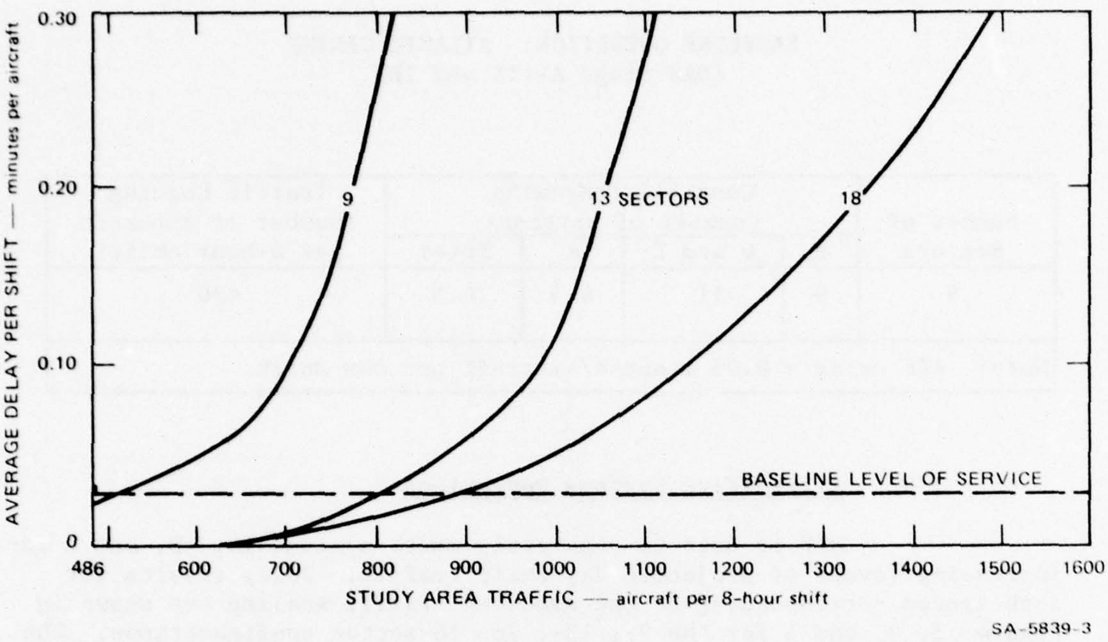

FIGURE 4 AVERAGE DELAY, ATLANTA CENTER, SYSTEM 1B, SMOOTHED TRAFFIC

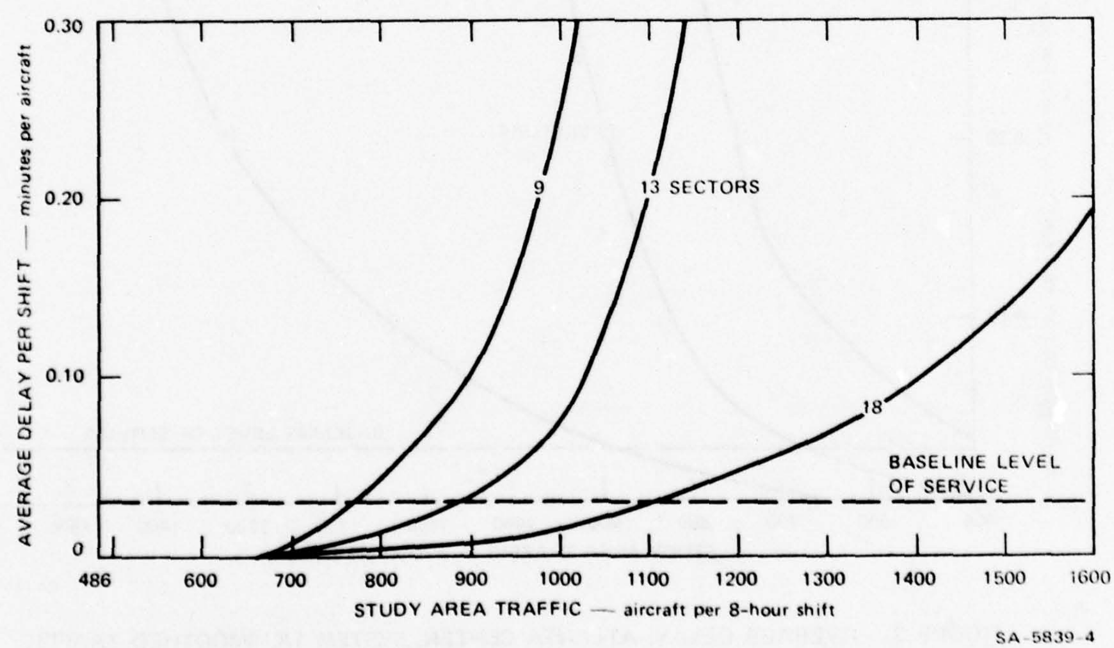

FIGURE 5 AVERAGE DELAY, ATLANTA CENTER, SYSTEM 2, SMOOTHED TRAFFIC

The study area capacities corresponding to the baseline level of delay for each configuration are obtained by inspection from these graphs. Multisector capacity is defined by the intersection of a delay curve with the horizontal baseline delay curve; this capacity is the maximum traffic handled at baseline delay. The resulting capacities are listed in Table 7 along with the corresponding sectorization and manning circumstances.

Table 7

ESTIMATED MULTISECTOR CAPACITY AND MANNING:
ATLANTA CENTER, SMOOTHED TRAFFIC

System	Number of Sectors	Traffic Capacity*	Traffic Factor†	Number of Controllers			
				R	D and T	A	Total
1A, NAS Stage A (2.5 men/sector)	9	480	0.99	9	9	4.5	22.5
	13	665	1.37	13	13	6.5	32.5
	18	880	1.81	18	18	9	45
1B, NAS Stage A (3.5 men/sector)	9	510	1.05	9	18	4.5	31.5
	13	805	1.66	13	26	6.5	45.5
	18	900	1.85	18	36	9	63
2, ETABS (2 men/sector)	9	710	1.46	9	9	0	18
	13	885	1.82	13	13	0	26
	18	1100	2.26	18	18	0	36

*Traffic capacity is the number of aircraft handled at current (1976) level of delay during the 8-hour study period.

†The traffic factor is the ratio of traffic capacity to the 1976 traffic base of 486 aircraft/8-hour shift.

With reference to the statistics shown for system 1A in Table 7, the 13-sector configuration is capable of handling at baseline delay a 37 percent increase over the baseline traffic of 486 aircraft per 8-hour shift. Each sector under System 1A operations is assigned one R controller, one D controller and one-half an A controller, resulting in 32.5 positions for the 13 sectors. Similar relationships between sectorization, traffic capacity, and the number of R, D, T, and A controller positions are shown in Table 7 for each configuration and system. The data in Table 7 are diagrammatically represented in Figure 6.

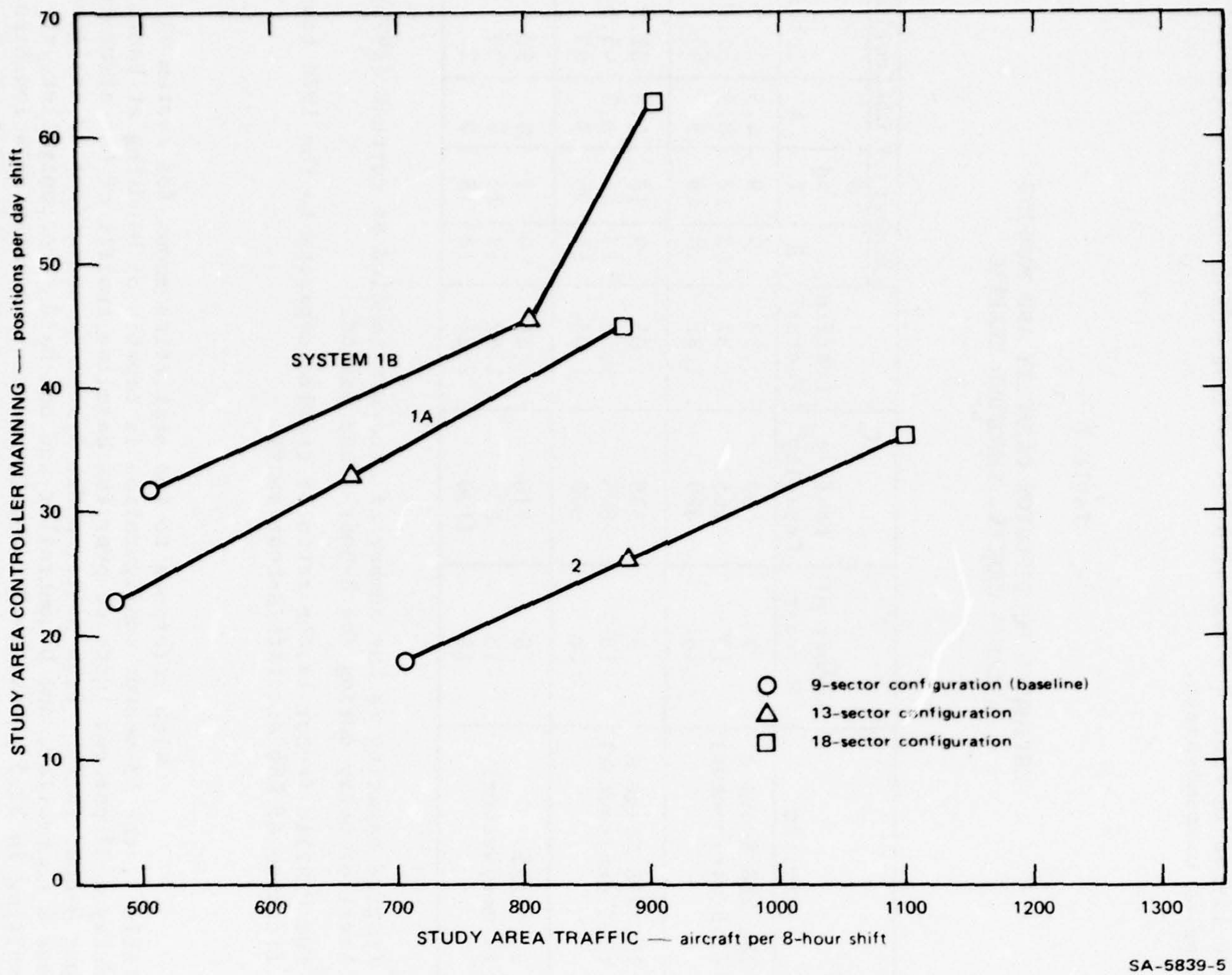

FIGURE 6 STUDY AREA CONTROLLER MANNING REQUIREMENTS AT BASELINE DELAY, ATLANTA CENTER, SMOOTHED TRAFFIC

3. Manning Requirements Estimates

a. Atlanta Center Manning Requirements

In order to compare system 1 and system 2 operations, the controller manning requirements for system 1 operations are developed by consolidating in an optimum manner the alternative manning strategies of system 1A (2.5 controller/sector) and system 1B (3.5 controller/sector). To facilitate the consolidation, the manning requirements of the current average delay shown in Figure 6 are transformed into those shown in Figure 7.

In the case of systems 1A and 1B, a transition from the current 3.5 men in two of the original 9 sectors to 2.5 men in 10 sectors is assumed to accompany the initial resectoring from nine to ten sectors. Inspection of Figure 6 reveals that switching completely to 2.5-man operations as sectors are split requires a smaller total number of control positions than a mixture of 2.5-man and 3.5-man operations.

Successive sector splits are then assumed to occur until the original 9 sectors are configured into 18, each manned at the 2.5-man level. The 18-sector arrangement represents the maximum number of sectors assumed to be configurable in the study area. Discussions with Atlanta Center personnel indicated that each of the original 9 sectors could be split, but that airspace limitations would preclude further resectorization. We assume there will be a transition to 3.5-man operations when this 18-sector limit is reached. However, a practical difficulty needs to be considered, as follows.

The transition to 18 sectors with 3.5 men per sector at the baseline level of delay is shown by the near vertical dotted curve in Figure 7. This sharp increase in staffing needs is accompanied by a negligible increase in traffic handling capability. This manning strategy is unrealistic and indicative of low marginal productivity returns. Therefore, we assume that a practical manning limit for maintaining baseline average delay will be reached at the 45-controller manning level (corresponding to a traffic factor of 1.81). More gradual manning increases (with increased delay) are extrapolated beyond the 1.81 traffic factor (dashed line in Figure 7) until the maximum staffing limit of 63 controller positions is reached at the 2.45 traffic factor. The 63 controller limit corresponds to the maximum bound on sectorization (18 sectors at 3.5 men per sector).

To summarize, the above manning strategy enables system 1 operations to maintain the baseline level of delay until the 1.81 traffic factor, beyond which additional delay is experienced even though manning increases. In comparison to system 1, the ETABS system 2 operation is shown to be able to maintain baseline delay until maximum sectorization is achieved at the 2.26 traffic factor with 36 controllers (18 sectors at 2 men per sector). Once the maximum sectorization and manning limits for each system are reached (that is, 63 men for system 1 and 36 for

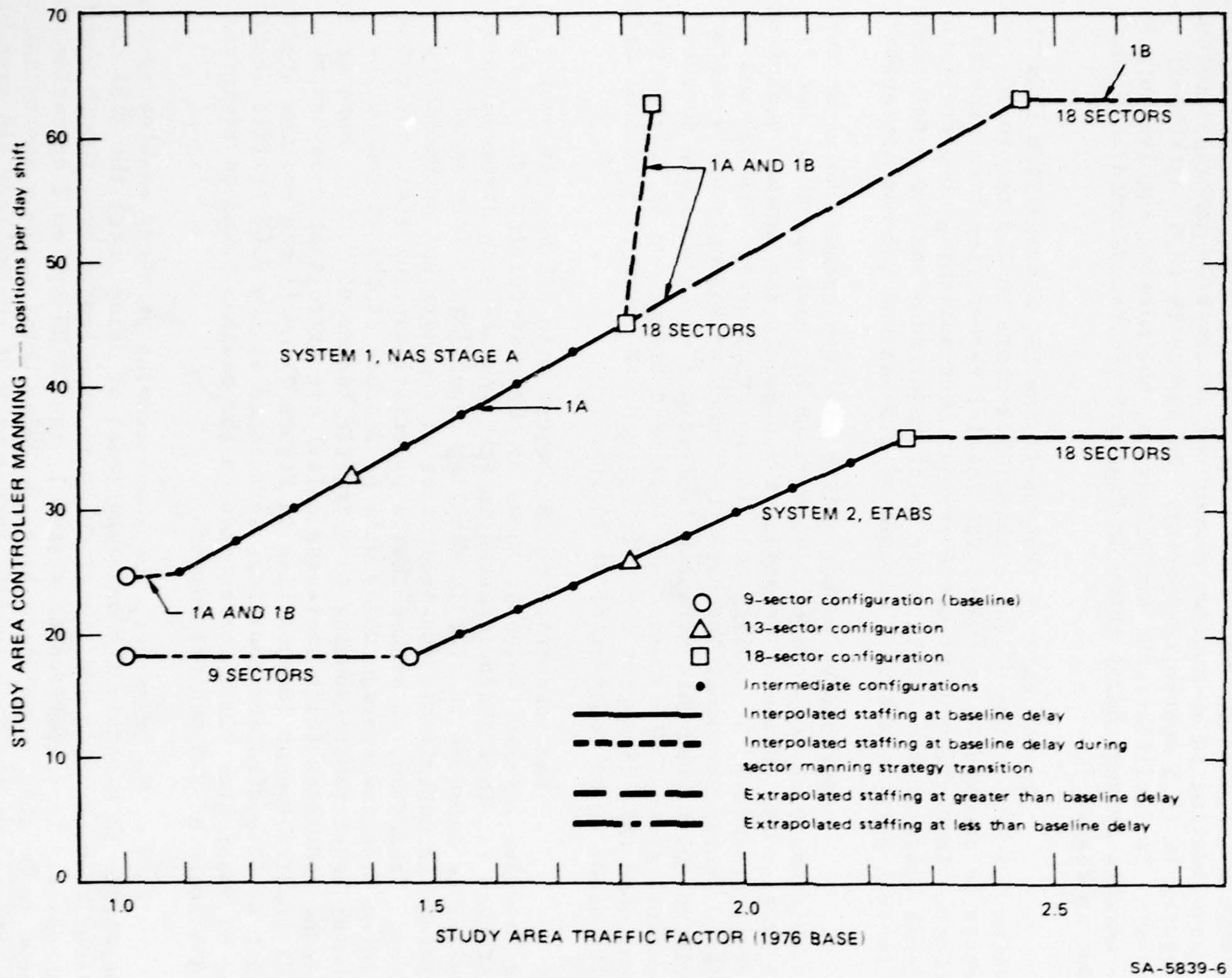

FIGURE 7 STUDY AREA CONTROLLER MANNING REQUIREMENTS ESTIMATES, ATLANTA CENTER, SMOOTHED TRAFFIC

system 2), further increases in traffic demand must be constrained, or achieved with greater delay, or both.

Figure 7 shows that system 2 can be maintained at the baseline 9-sector configuration with 18 positions as the traffic grows from the 1.0 to the 1.46 factor. During this period, the 2-man ETABS sector operations would operate with less than the baseline level of average delay.

Figure 7 also shows the interpolation of intermediate sector configurations (shown as dots) between the ATF modeled 9-sector, 13-sector, and 18-sector configurations. The traffic factors corresponding to each sectorization configuration, along with knowledge of the sector manning strategy, permits calculation of the associated number of R, D and T, and A controllers. The resulting relationships between traffic and manning requirements for systems 1 and 2 are tabulated in Table 8 for selected traffic factors. The manning versus traffic factors in Table 8 apply to the Atlanta Center on a facility-wide basis, not just

Table 8

ATLANTA CENTER GROWTH FACTOR ESTIMATES: SMOOTHED TRAFFIC

System	Traffic Factor*	Sector Factor*	Staffing Factor*		
			R	D and T	A
1. NAS Stage A	1.0	1.0	1.0	1.0	1.0
	1.2	1.24	1.24	1.02	1.24
	1.4	1.48	1.48	1.21	1.48
	1.6	1.73	1.73	1.42	1.73
	1.8	2.0	2.0	1.64	2.0
	2.0	2.0	2.0	2.09	2.0
	2.2	2.0	2.0	2.64	2.0
	2.4	2.0	2.0	3.18	2.0
	≥2.45	2.0	2.0	3.27	2.0
2. ETABS	1.0	1.0	1.0	0.82	0
	1.2	1.0	1.0	0.82	0
	1.4	1.0	1.0	0.82	0
	1.6	1.18	1.18	0.96	0
	1.8	1.42	1.42	1.16	0
	2.0	1.67	1.67	1.36	0
	2.2	1.92	1.92	1.57	0
	≥2.26	2.0	2.0	1.64	0

*1976 base.

to the study area. This application assumes that facility-wide sectorization, manning, and traffic growth will be distributed in direct proportion to that of the study area.

b. Los Angeles Center Manning Requirements

An analysis identical to that described for the Atlanta Center was carried out for the multisector study area of the Los Angeles Center. The results for the smoothed traffic scaling are shown in Figure 8. The corresponding facility-wide manning requirements are tabulated in Table 9 for selected traffic factors; supporting data are included in Appendix B.

The analysis of the Los Angeles Center operations varies from that documented as part of the previous case study report,[1] because resectorization has been carried out at the Los Angeles facility since the case study was conducted. The 1976 baseline study area configuration is 11 sectors, as opposed to 10 sectors used in the case study. However, the maximum sectorization limit has not changed, and is still at the 18-sector upper bound (based on discussions with Los Angeles Center personnel held during the case study). The minimum study area configuration is 9 sectors, as used in the case study. Other differences between the results of this research and that of the original case study are due to the use of an updated version of the ATF model and the use of computerized peaked and smoothed traffic scaling routines.

Figure 8 shows that manning requirements for system 1 can be minimized by carrying out a transition from the baseline 11-sector operations to 3.5-man operations before resectorization is conducted. (Recall that the Atlanta Center analysis, unlike the Los Angeles Center analysis, assumed a full resectorization before conducting manning strategy transitions.) The manning transition to 11 sectors with 3.5 men is completed at the 1.13 traffic factor. No further manning and sectorization adjustments are assumed to be practical to maintain current delay, and a linear extrapolation is used to project sector splitting effects accompanied by increased delays. The maximum sectorization bound of 18 sectors with 63 positions is reached at the 1.44 traffic factor by system 1.

System 2 resectorizations reach the maximum bound of 18 sectors with 36 positions at the 1.5 traffic factor. This manning maintains the baseline level of delay until the 1.5 traffic factor is reached.

c. National Manning Requirements

R, D and T, and A controller minimum manning requirements for the 20 domestic centers are obtained by arithmetically averaging the manning versus traffic relationships obtained for the Atlanta Center and the Los Angeles Center studies. These case study statistics are used

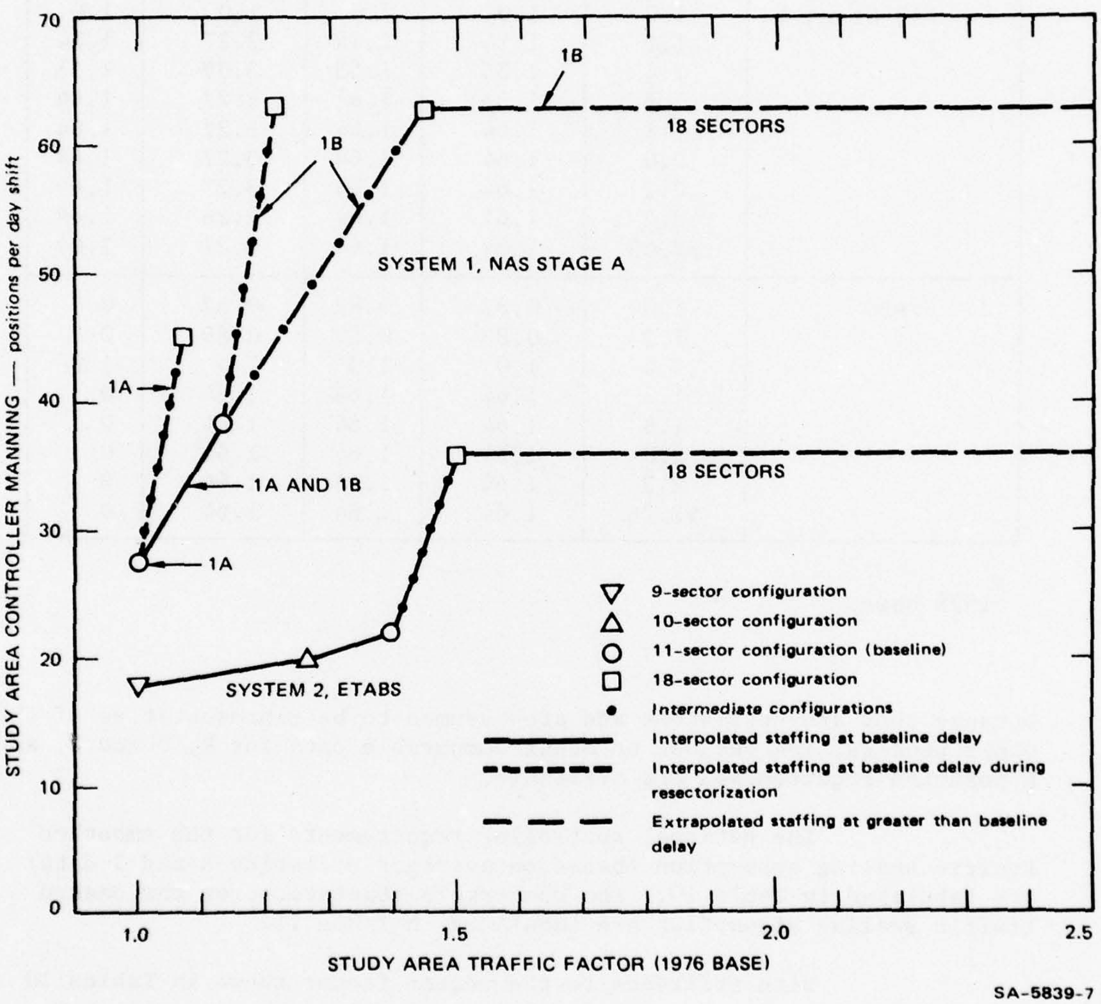

FIGURE 8 STUDY AREA CONTROLLER MANNING REQUIREMENTS ESTIMATES, LOS ANGELES CENTER, SMOOTHED TRAFFIC

Table 9

LOS ANGELES CENTER GROWTH FACTOR ESTIMATES: SMOOTHED TRAFFIC

System	Traffic Factor*	Sector Factor*	Staffing Factor*		
			R	D and T	A
1. NAS Stage A	1.0	1.0	1.0	1.0	1.0
	1.2	1.14	1.14	2.27	1.14
	1.4	1.55	1.55	3.09	1.55
	1.6	1.64	1.64	3.27	1.64
	1.8	1.64	1.64	3.27	1.64
	2.0	1.64	1.64	3.27	1.64
	2.2	1.64	1.64	3.27	1.64
	2.4	1.64	1.64	3.26	1.64
	≥2.45	1.64	1.64	3.27	1.64
2. ETABS	1.0	0.82	0.82	0.82	0
	1.2	0.89	0.89	0.89	0
	1.4	1.0	1.0	1.0	1.0
	1.6	1.64	1.64	1.64	0
	1.8	1.64	1.64	1.64	0
	2.0	1.64	1.64	1.64	0
	2.2	1.64	1.64	1.64	0
	≥2.26	1.64	1.64	1.64	0

*1976 base.

because they are consistent and are assumed to be representative of the other centers, and because no other comparable data for R, D and T, and A position requirements are available.

The national controller requirements for the smoothed traffic scaling assumption (based on averages of Tables 8 and 9 data) are tabulated in Table 10. The comparable statistics for the peaked traffic scaling assumption are tabulated in Table 11.

With reference to the sector factor shown in Tables 10 and 11, the upper bound on national sectorization shows a maximum increase of 82 percent in the number of sectors relative to the 1976 baseline number. This 1.82 sector growth factor is an average of the 2.0 upper sector bound assumed for Atlanta and the 1.64 bound assumed for Los Angeles.

Table 10

20-CENTER GROWTH FACTOR ESTIMATES: SMOOTHED TRAFFIC

System	Traffic Factor†	Sector Factor†	Staffing Factor*		
			R†	D and T†	A†
1. NAS Stage A	1.0	1.0	1.0	1.0	1.0
	1.2	1.19	1.19	1.65	1.19
	1.4	1.52	1.52	2.15	1.52
	1.6	1.69	1.69	2.35	1.69
	1.8	1.82	1.82	2.46	1.82
	2.0	1.82	1.82	2.68	1.82
	2.2	1.82	1.82	2.95	1.82
	2.4	1.82	1.82	3.22	1.82
	≥2.45	1.82	1.82	3.27	1.82
2. ETABS	1.0	0.91	0.91	0.82	0
	1.2	0.95	0.95	0.86	0
	1.4	1.0	1.0	0.91	0
	1.6	1.41	1.41	1.30	0
	1.8	1.53	1.53	1.40	0
	2.0	1.66	1.66	1.50	0
	2.2	1.78	1.78	1.61	0
	≥2.26	1.82	1.82	1.64	0

*The indicated staffing factor is the average of Atlanta and Los Angeles Centers' factor estimates.

†1976 base.

D. Baseline Staffing

The staffing factors in Tables 10 and 11 will be used in Section IV of this report to expand baseline staffing into national requirements corresponding to forecasts of traffic through 1999. The derivation of the 1976 baseline number of R, D and T, and A controllers for the 20 domestic centers is described in the following paragraphs.

1. R Controller Baseline Manning

An FAA manuscript of staffing at the 20 centers during 1976 includes actual on-board staffing and calculated staffing requirements.[7] Calculated staffing is based on manning requirements stipulated by FAA en route staffing standards.[8] The reported staffing statistics describe the number of fully qualified controllers (referred to as full performance

Table 11

20-CENTER GROWTH FACTOR ESTIMATES: PEAKED TRAFFIC

System	Traffic Factor†	Sector Factor†	Staffing Factor*		
			R†	D and T†	A†
1. NAS Stage A	1.0	1.0	1.0	1.0	1.0
	1.1	1.11	1.11	1.43	1.11
	1.2	1.31	1.31	1.77	1.31
	1.3	1.54	1.54	2.09	1.54
	1.4	1.77	1.77	2.41	1.77
	1.5	1.82	1.82	2.59	1.82
	1.6	1.82	1.82	2.82	1.82
	1.7	1.82	1.82	3.05	1.82
	≥1.80	1.82	1.82	3.27	1.82
2. ETABS	1.0	0.91	0.91	0.82	0
	1.1	0.93	0.93	0.84	0
	1.2	0.96	0.96	0.87	0
	1.3	0.98	0.98	0.89	0
	1.4	1.07	1.07	0.97	0
	1.5	1.49	1.49	1.37	0
	1.6	1.61	1.61	1.47	0
	1.7	1.81	1.81	1.63	0
	≥1.71	1.82	1.82	1.64	0

*The indicated staffing factor is the average of Atlanta and Los Angeles Centers' factor estimates.

†1976 base.

level or FPL controllers) as well as controllers who are training to become FPL controllers (referred to as developmental controllers). However, the staffing statistics do not distinguish between R, D and T, and A position requirements. For the purpose of this research, an estimate of the individual position manning requirements was made using the sector-by-sector, hour-by-hour actual on-board manning data reported[7] for the 1976 busy day for each of the 20 facilities.

An analysis of 1976 busy-day sector utilization and R-position manning is summarized in Table 12. A total of 660 sectors were reported to be in operation, while an additional 11 sectors were not active (that is, did not handle traffic and were not manned). To estimate R-position requirements, the number of hours that sectors were manned during each 8-hour shift were studied. This study took into account the possible effects of staggered shift assignments (for example, starting different controller teams at successive one-hour increments, such as at 7:00,

Table 12

ESTIMATED R-POSITION SHIFT MANNING REQUIREMENTS
20 Centers, 1976 Busy Day

Center	Number of Active Sectors†	Number of Manned R Positions Required* by 8-Hour Shift (man-shifts)			
		Midnight‡ Shift	Day§ Shift	Evening‡ Shift	Total Busy Day
Kansas City, ZKC	29	9	29	28	66
Washington, ZDC	35	8	35	35	78
New York, ZNY	45	20	45	45	110
Chicago, ZAU	38	10	38	38	85
Indianapolis, ZID	35	11	35	35	81
Minneapolis, ZMP	28	12	28	27	67
Cleveland, ZOB	45	19	45	45	109
Boston, ZBW	29	15	29	29	73
Seattle, ZSE	17	6	17	15	38
Denver, ZDV	29	13	29	29	71
Salt Lake City, ZLC	21	10	21	21	52
Jacksonville, ZJX	36	10	36	35	81
Miami, ZMA	27	8	27	27	62
Memphis, ZME	34	14	34	32	77
Atlanta, ZTL	40	11	40	39	90
Albuquerque, ZAB	33	6	33	26	65
Fort Worth, ZFW	41	11	41	41	93
Houston, ZHU	37	12	37	37	86
Los Angeles, ZLA	35	12	35	34	81
Oakland, ZOA	26	13	26	26	65
Total	660	230	660	644	1,534

*The R-position estimates are based on 1976 sector manning for the 37th busiest day by center, as reported in Ref. 7.

†Active sectors are those sectors that were reported to handle traffic on the 1976 busy day; 11 additional sectors reportedly handled no traffic on the busy day, and are not included in this table.

‡The indicated number of manned R positions is the number of sectors reporting an actual on-board staff ≥ 0.5 men per 8-hour shift during the midnight or evening shifts.

§The indicated number of manned R positions is the total number of active sectors during the day shift.

8:00, and 9:00 a.m.) and considered the need to maintain a controller on board for 8 hours once he or she is assigned to duty.

The procedure used to estimate baseline R controller requirements is demonstrated with the aid of Figure 9, which shows the actual on-board manning (exclusive of A positions) reported for two hypothetical sectors. During the midnight shift, Sector 1 is not in operation during the first 4 hours but is manned at two positions during the remaining 4 hours. One of the two positions must be an R position. Therefore, one R controller would need to be assigned to duty during the 8-hour midnight shift, although only 4 hours of his or her time are actually required at Sector 1. Similarly, both the day and evening shifts for Sector 1 would each require one R controller on duty although the sector is not continuously manned during the evening shift. Sector 1 therefore requires that three R-controller shifts be manned during the busy day.

Sector 2 manning exemplifies a situation in which two R controller shifts (rather than three shifts) would be required during the busy day. In this case, a controller team is assumed to begin its day shift during the last hour (7:00 a.m.) of the nominal midnight shift; an evening shift begins 8 hours later. Such offsetting of shift start times is common at centers experiencing early morning traffic "rushes."

Since the precise manning and shift scheduling strategies actually used at each center are not known, the following rule of thumb is used to approximate R controller requirements: one R controller shift must be manned for any sector reporting an actual on-board staff of at least 0.5 controllers during a shift. For example, Sector 2 in Figure 9 shows a staff of 0.25 controllers per shift during the midnight shift (that is, 2 controllers per 8-hour shift), and, according to the above rule of thumb, R controller midnight shift manning would not be required because of the offset shift. This rule was applied to the actual on-board busy-day manning reported for each sector for each facility in order to obtain the R controller shift manning requirements in Table 12.

Table 12 shows that at least 1,534 R controllers are needed to man sectors for the 1976 busy day at the 20 centers. Of the total number of R controllers, 15 percent are required for midnight shift operations, while the remainder are almost evenly split between day shift (43 percent) and evening shift (42 percent) operations. The low midnight shift requirements are indicative of light traffic activity, during which selected groups of two or more sectors typically are combined into one sector (according to current facility practices).

2. D and T Controller Baseline Manning

Using the 1976 busy-day actual on-board manning reported for each of the 20 centers, the number of total controller-hours (exclusive of A controllers) and the number of R controller-hours spent in manning all sectors on the busy days were tabulated. The number of R controller-hours is equal to the number of hours each sector was manned by at least

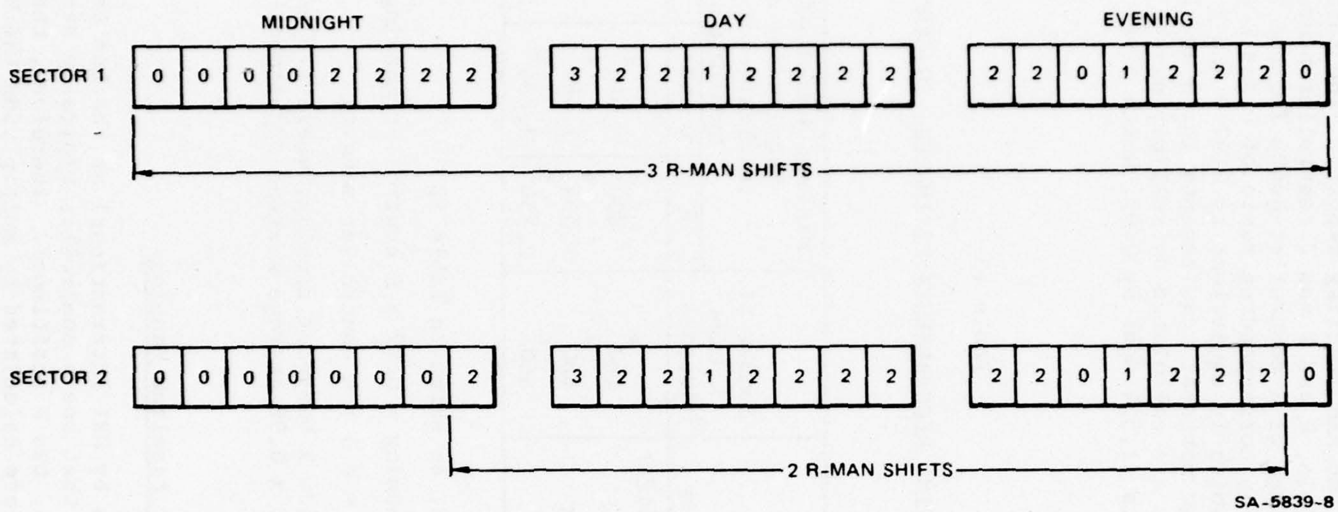

FIGURE 9 EXAMPLE OF ACTUAL ON-BOARD SECTOR MANNING REPORT

one controller. The total controller-hours is equal to the sum of the number of controllers manning each sector during each hour of operation; this is summarized in the FAA staffing report.[7] The total number of controller-hours (that is, R and D and T controller-hours) was found to be 23,030, and the number of R controller-hours for the 20 busy days was found to be 11,698. The corresponding ratio of D and T controllers to R controllers is 1.97, which is equivalent to 0.97 D and T controllers for each R controller. The national requirements for D and T controllers for the 1976 busy days are calculated by multiplying the national R controller requirements (1,534 men) by 0.97, which gives 1,488 controllers, as shown in Table 13.

Table 13

MANNING AND STAFFING REQUIREMENTS ESTIMATES, 20 CENTERS, 1976

Requirement Category	Number of Active Sectors	Minimum Number of Controllers Required by Position (exclusive of advanced training needs)			
		R	D and T	A	Total
1976 busy-day (day-shift) manning	660*	600*	640†	330‡	1,630
1976 busy-day manning	660*	1,534*	1,488†	767‡	3,789
1976 annual staffing	660*	2,356§	2,286§	1,178§	5,820

*Estimated from Ref. 7, as shown in Table 12.

†D and T controller manning = 0.97 x R controller manning.

‡A controller manning = 0.5 x R controller manning.

§Annual staffing = 1.536 x busy-day manning, where 1.536 = 1.6 annual and sick leave factor x 0.96 average weekend adjustment factor.

3. A Controller Baseline Manning

Observations by SRI International at the Los Angeles and Atlanta Centers found that one A controller typically services two sectors (or, equivalently, two R positions). Therefore, the A-controller national requirements are calculated by multiplying the R-controller requirements (1,534 men) by 0.5, which gives 767 A controllers as shown in Table 13.

4. Baseline Annual Staffing

The data calculated above for busy-day manning requirements assumes that each controller is on duty for 8 hours. The FAA staffing standards allow this minimum manning to be increased by 20 percent to allow for controller relief unless "excess capacity" provides sufficient relief time. The excess capacity accounts for the time controllers are kept on duty (because of the 8-hour shift rule), although their services may not be needed for each hour of the shift (because of off-peak hourly traffic loadings). A study of the 1976 busy-day reports found that excess capacity dominated the manning situation. Hence, the 20-percent relief manning allowance is not used. As a result, the busy-day manning requirements are as shown in Table 13 under the assumption that excess capacity is sufficient for controller relief allowances.

To calculate annual sector staffing requirements, the staffing standards allow a 60-percent increase in the busy-day manning to account for the 7-day workweek plus annual and sick leave. A study of the 1976 busy-day reports[7] found that the average weekend adjustment factor of 96 percent for the 20 centers allowed for a decrease in staffing needs; this decrease accounts for the reduction in traffic activity and manning needs occurring during the weekends. National annual controller staffing requirements are calculated by multiplying busy-day manning requirements by the 1.60 staffing adjustment factor and by the 0.96 weekend adjustment factor as shown in Table 13. This calculation gives a total requirement for 5,820 controllers in 1976, of which 41 percent are R controllers, 39 percent are D and T controllers, and 20 percent are A controllers. These estimates represent the minimum number of controllers required to operate the active sectors, and do not include allowances for advance training needs.

The baseline controller requirements are compared to the actual on-board staff in Table 14. The actual staffing is reported[7] according to the number of FPL and developmental controllers on board at the 20 centers for the 1976 baseline year. Table 14 compares the on-board 5,131 FPL staff members against the R controller requirements, and the on-board 2,337 developmentals against the D controller, A controller, and advance recruitment requirements (the latter will be estimated in the next sections of this report). A total of 7,468 controllers are actually on board, which is 1,648 more than the estimated 5,820 requirement. The difference between requirement and on-board staff is due to the exclusion of advanced recruitment estimates in the data given in Table 14.

E. Traffic Forecast

Traffic forecasts for FY 1977-99 were provided by the FAA[9] and are listed in Table 15. Traffic estimates for the 20 domestic centers are obtained by subtracting the nondomestic annual traffic forecast from the total annual traffic forecast. Traffic factors for each fiscal year from 1977 through 1997 are calculated relative to the 1976 baseline year.

Table 14

20-CENTER 1976 CONTROLLER STAFFING

	Controller Requirement Estimates (number of persons)	Actual On-Board Controllers (number of persons)
Controller type		
R	2,356	5,131 (FPL)
D	2,286	
A	1,178	2,337 (developmental)
Advance recruitment	--	
Total	5,820	7,468

Table 15

TRAFFIC FORECAST ESTIMATE, 20 CENTERS

		Thousands of Aircraft Handled*		
Fiscal Year	National	Nondomestic†	Domestic‡	Domestic Traffic Factor (FY 1976 base)
1976	23,923	1,057	22,866	1.0
1977	25,706	1,192	24,514	1.07
1978	26,710	1,236	25,474	1.11
1979	27,728	1,285	26,443	1.16
1980	28,936	1,338	27,598	1.21
1981	30,745	1,413	29,332	1.28
1982	32,153	1,484	30,669	1.34
1983	32,963	1,529	31,434	1.37
1984	33,927	1,580	32,347	1.41
1985	35,066	1,636	33,430	1.46
1986	36,290	1,695	34,595	1.51
1987	37,752	1,766	35,986	1.57
1988	39,161	1,820	37,341	1.63
1989	40,580	1,879	38,701	1.69
1990	42,038	1,937	40,101	1.75
1991	43,540	1,999	41,541	1.82
1992	45,083	2,061	43,022	1.88
1993	46,671	2,123	44,548	1.95
1994	48,299	2,188	46,111	2.02
1995	49,973	2,253	47,720	2.09
1996	51,669	2,322	49,347	2.16
1997	53,410	2,389	51,021	2.23
1998	55,170	2,457	52,713	2.31
1999	56,971	2,527	54,444	2.38

*Data source: Ref. 9.

†Aircraft handled, nondomestic, are traffic estimates for the Alaskan region (Anchorage ARTCC), Pacific region (Honolulu, Guam ARTCCs), Balboa ARTCC, and San Juan ARTCC.

‡Aircraft handled, 20 domestic centers, equals the (aircraft handled, national) minus (aircraft handled, nondomestic).

Source: FAA

IV PROJECTIONS OF NATIONWIDE EN ROUTE STAFFING LEVELS

Previous research[1-3,10] has indicated that one of the most significant potential benefits associated with the introduction of an Electronic Tabular Display Subsystem is the reduction of the staffing levels relative to the staffing levels that would occur without this technology. For this reason, a significant portion of the analyses has been devoted to the development of projections of the national staffing levels for the study period of FY 1977-99. This section describes the methods and assumptions used to develop these projections and compares the projection of staffing levels for the current NAS Stage A system to that of a nominally defined ETABS implementation scenario. This "base case" implementation scenario is based on the assumption that ETABS will be 50 percent deployed by the end of 1984 and 100 percent deployed by the end of 1985. The effects of changes to the base case implementation scenario, such as a deferral of ETABS deployment, were also examined during this project and are detailed in a later section.

The existing 20 domestic en route centers are actually manned by two distinct staff organizations; Air Traffic Service (AAT) staff and Airway Facilities Service (AAF) staff. Each staff organization has its own operational responsibilities and management structure. In addition, there also exist significant variations of job skills and categories between the two staff organizations. The Air Traffic Service staff operates the ATC system, while the Airway Facilities Service staff maintains the ATC equipment. Because of the dissimilitude between AAT and AAF personnel requirements, separate staffing projections have been made for each of these two organizations.

A. Base Case ETABS Implementation Scenario

This section will compare the projected staffing levels associated with two system implementation scenarios. The first of these two implementation scenarios is the "do nothing" scenario and is based upon the assumptions that neither ETABS nor any other controller work-load-reducing technology will be introduced before the year 2000, and that ATC operations will not change significantly during this period. The second implementation scenario is a nominally defined base case development and deployment of ETABS. In this scenario ETABS engineering and development takes place during FY 1978-80 period and the initial procurement of ETABS equipment occurs from FY 1982 to 1985. Operational deployment of ETABS is assumed to require two years and it will be 50 percent implemented by the end of 1984 and 100 percent implemented during 1985. In the base case implementation scenario it is assumed that there are no constraints to reducing the number of en route sectors if controller workload is

reduced. However, it is assumed that the size of the controller work force can only be reduced through normal washout and attrition. The controller requirements for both the current NAS Stage A system and the base case ETABS deployment are demonstrated for the smoothed traffic projections described in the previous section.

B. Air Traffic Service Staffing Projections

Apart from the air traffic controllers, the en route AAT staff is also composed of other personnel who support control operations. The other AAT staff includes management, supervisory, training, administrative, and clerical personnel. In the previous section, relationships between traffic activity and controller staffing requirements have been developed. However, the staffing requirements for the other AAT staff are not directly related to traffic activity. Therefore, different techniques were used to project the staffing levels for AAT controllers and the other AAT staff members.

1. Air Traffic Controllers

The air traffic staffing requirements described in Section III of this report relate the need for controllers at three different levels of qualification (R, D and T, and A positions) to traffic activity levels. These relationships were used in conjunction with a forecast of traffic activity to estimate the controller staffing and ATC sector requirements for each year during the FY 1977-99 period. These estimates for the current NAS Stage A system continuance and for the basic ETABS deployment are shown in Table 16. These estimates include only those controllers who routinely man control positions; they do not include those controllers assigned primarily to administrative or training responsibilities.

a. Controller Advance Recruitment (CAR) Model

The rapid installation of new ATC technology can reduce controller staffing requirements. However, in this study controller staff reductions are assumed to be accomplished through normal attrition and washout and modification of the recruitment rate. In addition, the controller training and qualification processes also affect the actual staffing levels and must be accounted for. At any given time, the controller staff is composed of full performance level (FPL) controllers as well as developmental controllers. The developmental controllers range from those who are not qualified to operate any positions to those who are qualified to work A positions, D and T positions, and even some R positions. It is therefore not appropriate to consider the estimates of annual controller staffing requirements as projections of controller staffing levels, because these requirements do not account for the controller training process, normal washout and attrition, and the factors constraining manpower reduction.

Table 16

20-CENTER MINIMUM OPERATIONAL REQUIREMENTS
Staffing and Sectorization End-of-Year Minimum Requirements

Fiscal Year	Current NAS Stage A Continuance						ETABS Base Case Deployment					
	Number of Controllers Required				Number of		Number of Controllers Required				Number of	
	R	D & T	A	Total	NAS/FSP Sectors	ETABS Sectors	R	D & T	A	Total	NAS/FSP Sectors	ETABS Sectors
1976	2,356	2,286	1,178	5,820	660	0	2,356	2,286	1,178	5,820	660	0
1977	2,512	2,806	1,256	6,574	703	0	2,512	2,806	1,256	6,574	703	0
1978	2,602	3,103	1,301	7,006	728	0	2,602	3,103	1,301	7,006	728	0
1979	2,714	3,474	1,357	7,545	760	0	2,714	3,474	1,357	7,545	760	0
1980	2,842	3,829	1,421	8,092	796	0	2,842	3,829	1,421	8,092	796	0
1981	3,114	4,229	1,557	8,900	872	0	3,114	4,229	1,557	8,900	872	0
1982	3,347	4,572	1,673	9,592	937	0	3,347	4,572	1,673	9,592	937	0
1983	3,464	4,743	1,732	9,939	970	0	3,464	4,743	1,732	9,939	970	0
1984	3,601	4,937	1,800	10,330	1,008	0	3,002	3,530	900	7,432	504	337
1985	3,701	5,052	1,850	10,603	1,036	0	2,645	2,347	0	4,992	0	741
1986	3,801	5,166	1,900	10,867	1,064	0	2,887	2,570	0	5,457	0	808
1987	3,921	5,303	1,960	11,184	1,098	0	3,177	2,838	0	6,015	0	890
1988	4,027	5,409	2,013	11,449	1,128	0	3,364	3,006	0	6,370	0	942
1989	4,119	5,485	2,059	11,663	1,154	0	3,449	3,074	0	6,523	0	966
1990	4,211	5,560	2,105	11,876	1,179	0	3,534	3,143	0	6,677	0	990
1991	4,287	5,673	2,143	12,103	1,201	0	3,635	3,223	0	6,858	0	1,018
1992	4,287	5,824	2,143	12,254	1,201	0	3,727	3,291	0	7,018	0	1,044
1993	4,287	6,000	2,143	12,430	1,201	0	3,834	3,371	0	7,205	0	1,074
1994	4,287	6,188	2,143	12,618	1,201	0	3,939	3,454	0	7,393	0	1,103
1995	4,287	6,404	2,143	12,834	1,201	0	4,038	3,542	0	7,580	0	1,131
1996	4,287	6,620	2,143	13,050	1,201	0	4,137	3,630	0	7,767	0	1,158
1997	4,287	6,836	2,143	13,266	1,201	0	4,240	3,714	0	7,954	0	1,187
1998	4,287	7,083	2,143	13,513	1,201	0	4,287	3,749	0	8,036	0	1,201
1999	4,287	7,299	2,143	13,729	1,201	0	4,287	3,749	0	8,036	0	1,201

In order to develop staffing projections that are sensitive to these factors, the Controller Advance Recruitment (CAR) model was developed. This model is used to determine the national annual recruitment needs for the en route ATC system.

Model Structure--The CAR model was designed to meet the particular information and analysis needs of this study, which call for distinguishing the staffing needs of current NAS Stage A and ETABS operations. For this reason its structure in some respects is different from that of the FAA's Advance Recruitment Model.[8] The latter model is designed for current system operating requirements, but is not applicable to ETABS operations.

The CAR model is a deterministic model that calculates the number of new controllers that should be hired at some "present" time in order to adequately meet future controller requirements. This problem of determining how many controller trainees to hire at a given time is, in many respects, similar to an inventory problem, and the structure of the CAR model is similar to that of a deterministic inventory model.

In an inventory model, the rate of ordering new stock is usually the primary means of controlling the inventory level over time. A simple model of this process could be constructed as:

Inventory at end of period	= inventory at beginning of period
	+ stock ordered during period
	- fulfilled demand for stock during period.

The amount of stock ordered during a time period is generally determined so as to maintain an inventory level that allows the demand for a product to be met. In an analogous fashion, new controllers are hired at a rate that is sufficient to ensure that there are enough controllers to operate the ATC system in a safe, expeditious, and efficient manner. A simple model of this process is the same as the inventory model:

Required number of controllers at end of period	= number of controllers at beginning of period
	+ number of controllers hired during period
	- number of controllers who have quit, retired, been reassigned to noncontroller duties, or the like, during period.

If we can make reasonable estimates of the values of the three variables other than the number of controllers hired, this variable can be easily found.

The simple model described above does not account for many important factors. One of the most important of these factors is the training delay between the time the new controllers are hired and the time that they become qualified to operate various control positions. (In the inventory problem this time delay can be considered to be analogous to the interval between the time when a product is ordered and when it is actually delivered.) The number of controllers to be hired at any one time should be related therefore not to present manpower needs, but rather to the manpower requirements that will occur after the controller training period. For this reason the CAR model is time-based so that all manpower status information is updated on a quarterly basis.

Another factor that must be accounted for when determining controller hiring needs is the fact that a controller progresses through various levels of qualifications before becoming a fully qualified controller. At these lower levels of qualification the controller can operate some of the positions within his area of specialty and is productive (recall that not all control positions must be manned by fully qualified controllers). For example, a developmental controller is typically capable of manning all of his area's A positions within his first year of training, some D positions after two years of training, all D positions and some R positions after about three years of training, and all positions after four years of training. In order to account for these differences, the CAR model bases recruitment decisions on future R, D and T, and A position staffing requirements, rather than total controller requirements alone. The three conditions that must be satisfied by the hiring rate are:

$$H_t \geq R_{t+r} - C_{t+r} \tag{1}$$

$$H_t \geq R_{t+d} + D_{t+d} - C'_{t+d} \tag{2}$$

$$H_t \geq R_{t+a} + D_{t+a} + A_{t+a} - C''_{t+a} \tag{3}$$

where:

H_n = number of new controllers that should be hired at the beginning of Quarter n ($H_n \geq 0$).

R_n, D_n, A_n = number of controllers qualified to man R, D and T, and A positions, respectively, that are required at the beginning of Quarter n.

C_n, C'_n, C''_n = number of controllers qualified to man R, D and T, and A positions, respectively, that would be available at the beginning of Quarter n if no new controllers were hired during the present quarter. The number of available controllers for any position includes all currently qualified controllers as well as those hired within the respective training periods in the future.

r, d, a = number of quarters of training required for a new controller to become qualified to work respectively at R, D and T, and A positions.

Note that these three conditions are formulated in a progressive manner. This is because controllers become progressively qualified to operate at more control positions without losing their capability to man positions that require a lesser degree of qualification. Thus an A position can be manned by an FPL who also can man D, T, or R positions.

The number of new controllers that should be hired at the beginning of any year should be the minimum number required to satisfy these three conditions. This value can be obtained by solving all three inequalities and selecting the largest value of H_t. The condition that results in the largest value of H_t is the constraining condition. In this model, the implementation of ETABS would have the effect of eliminating the condition represented by Eq. (3) because staffing the requirements for the A positions are reduced to zero. If this has been the constraining condition, the relaxation of the constraint will result in the reduction of controller recruitment needs.

The CAR model structure also accounts for other major factors that influence controller hiring rates. Among these are the current makeup of the controller work force, the controller training cycle, future controller requirements, washout and attrition rates, availability rates, and controller qualification levels. Each of these factors is briefly described below.

<u>Makeup of the Controller Work Force</u>--The CAR model requires input of the initial conditions regarding the makeup of the controller work force. This input includes the number of en route controllers who are at various quarters of training. The CAR model is initiated with the makeup of the actual on-board developmental and FPL controller work force for the 20 centers at the end of FY 1976. The number of developmental controllers (totaling 2,337 persons) in each quarter of training were supplied by the FAA and are shown in Table 17; also shown is the count of FPL controllers. The data shown in the table correspond to the controller statistics reported previously in Table 14.

<u>Air Traffic Controller Training Cycle</u>--A major reason for developing the CAR model was to specifically account for the training time required at different stages of a developmental's progression to becoming an FPL. Using information from an FAA training plan,[11] a generalized 13-phase en route training schedule was identified. This schedule, based on a 4-year training cycle, is shown in Table 18. Since the CAR model progresses incrementally through time on a quarter-by-quarter basis, the training time requirements also were translated into this form and are shown in Table 19.

Table 17

BASELINE CONTROLLER STAFF

Quarter in Training	Number of Actual On-board Controllers at End of FY 1976
1	269 developmentals
2	108 developmentals
3	229 developmentals
4	68 developmentals
5	222 developmentals
6	71 developmentals
7	184 developmentals
8	35 developmentals
9	354 developmentals
10	127 developmentals
11	294 developmentals
12	71 developmentals
13	130 developmentals
14	44 developmentals
15	109 developmentals
16	22 developmentals
≥ 17	5,131 FPLs

Future Controller Requirements--The future controller requirements essentially drive the CAR model in that they determine the hiring decision in the present quarter. The model structure differentiates between A-man, D-man (and T-man), and R-man position requirements and accounts for the fact that even during the 4-year training cycle the developmental controller does man certain control positions and is productive (that is, not all positions must be manned by an FPL). At each discrete quarterly interval the model determines how many controllers qualified to man a given position type, such as R position, will be available at a certain time in the future. These projections of controller availability account for the progression of developmental controllers to higher qualification levels, washout rates, attrition rates, and availability rates. The number of controllers available to man a given type of position is then compared to the number of controllers required for that position. If a shortage of controllers is projected to occur, the model calculates the number of controllers that should be hired 4 years (16 quarters) in advance to alleviate that shortage, after accounting for controller washout during training. The future controller

Table 18

ATC EN ROUTE SPECIALIST TRAINING PROGRAM

	Phase	Duration (wks/hrs)	Training Time (hours)	Cumulative Time (weeks)
Initial training	1	2/80	80	2
	2	6/240	240	8
	3	8/320	320	16
	4	2/80	80	18
	5	6/240	240	24
	6	6/240	240*	30
A qualified	7	51/2,040	15	81
	8	10/400	240	91
	9	5/200	120†	96
D qualified	10	8.320	240‡	104
	11	26/1,040	240	130
	12	26/1,040	120†	156
R qualified	13	52/2,080	240‡	208

*Based on 6 sectors.

†Based on 2 sectors.

‡Based on 4 sectors.

requirements are initially determined on an annual basis but are converted to quarterly requirements within the model by a simple interpolation process.

Controller Qualification Levels--During the 4-year training cycle, a developmental controller gradually becomes qualified to work under only general supervision at certain positions within a specific area. A developmental controller either is qualified to operate a given position, or he is not. The CAR model therefore describes a controller's qualification level as a 0-1 step function for each of the three principal position categories: (1) A controller, (2) D and T controller, and (3) R controller. The qualification levels during the training cycle, for each of these position categories, are shown in Table 20.

Table 19

ATC TRAINING SCHEDULE

	Quarter	Phase	Training Time (hours)	Quarterly Availability Rate*	Quarterly Washout and Attrition Rates†	GS Grade
Initial training	1	1,2,3(1-5)‡	520	0.0000	0.0121	7
	2	3(6-8),4,5,6(1-2)	520	0.0000	0.0121	7
	3	6(3-6),7(1-9)	163	0.6865	0.0121	7
A qualified	4	7(10-22)	4	0.9923	0.0121	7
	5	7(23-35)	4	0.9923	0.0113	9
	6	7(36-48)	4	0.9923	0.0113	9
	7	7(49-51),8(1-10)	241	0.5365	0.0113	9
	8	9(1-5),10(1-8)	360	0.3077	0.0113	9
D qualified	9	11(1-13)	120	0.7692	0.0080	11
	10	11(14-26)	120	0.7692	0.0080	11
	11	12(1-13)	60	0.8846	0.0080	11
	12	12(14-26)	60	0.8846	0.0080	11
R qualified	13	13(1-13)	60	0.8846	0.0100	12
	14	13(14-26)	60	0.8846	0.0100	12
	15	13(27-39)	60	0.8846	0.0100	12
	16	13(40-52)	60	0.8846	0.0100	12
	≥ 17	FPL	0	1.0000	0.0123	13

*The indicated availability rates are measured in units of time available for control work per controller per quarter.

†The indicated *washout and attrition rates are measured* in units of persons lost per controller per quarter. Washout rates apply to developmental controllers during the first 16 quarters; the *attrition rate*, 0.0123, applies to FPL controllers in quarter 17 and thereafter.

‡Number in parenthesis indicates the duration in weeks included as part of the phase shown. For example, weeks 1-5 of phase 3 occur during the first quarter, and weeks 6-8 of phase 3 occur during the second quarter.

Table 20

CONTROLLER QUALIFICATION LEVELS

Quarter in Training Cycle	Position Category		
	A	D and T	R
1	0	0	0
2	0	0	0
3	0	0	0
4	1	0	0
5	1	0	0
6	1	0	0
7	1	0	0
8	1	0	0
9	1	1	0
10	1	1	0
11	1	1	0
12	1	1	0
13	1	1	1
14	1	1	1
15	1	1	1
16	1	1	1

Note: 0 indicates controller is not yet qualified at this position category.

1 indicates controller is qualified at this position category.

Controller Availability Rates--During the 4-year training cycle the percentage of time that is devoted to training will not always be 100 percent, thus allowing the developmental controller some time to perform productive work, provided that he is qualified to operate a position. In the CAR model we have defined controller availability as the proportion of time that a controller is not engaged in training. Since controller vacation, sick leave, and other unproductive time is accounted for in determining controller staffing requirements, they are not included in the determination of controller availability. The controller availability rates per quarter during the 4-year training cycle are shown in Table 19. In order to determine the potential work contribution of developmental controllers during a particular quarter of training, the

CAR model multiplies the availability rate for that quarter by the qualification level for the various work assignments. This product is then multiplied by the number of controllers staffed in that particular quarter of training to obtain the number of controllers available for operational duty (exclusive of training program needs).

Washout Rates--A washout rate is the rate at which developmental controllers exit from the training program before completion. In the CAR model a constant washout rate is associated with each of the 16 quarters of the training cycle. As an example of the use of these rates, suppose that, on a national basis, 200 developmental controllers had just completed three quarters of training and that the washout rate for the fourth quarter was 1.2 percent. In this case 3 controllers would wash out during the fourth quarter of training, while 197 would successfully have completed the first year of the training cycle. The washout rates that were used in the analyses were furnished to us by the FAA and are listed in Table 19.

Attrition Rate--The attrition rate is the average rate per quarter at which FPLs leave the controller work force. This action may occur because of retirements, promotions or transfers to noncontroller type jobs within the agency, leaving the agency, or similar actions. Again, the attrition rate used in the analyses (1.23 percent per quarter as shown in Table 19) was determined by the FAA from an examination of historical data. The use of a constant attrition rate presupposes that controller attrition will not dramatically change during the study period. Changes to the controller retirement plan, disability plan, or other change can, of course, cause this rate to vary. However, considering the direction that such changes will probably take, the use of a constant attrition rate based on historical data is probably a reasonably conservative approach.

b. Projections of Air Traffic Controller Hiring and Staffing

The CAR model was used to project the air traffic controller staff that would be associated with the current ATC system as well as the basic ETABS implementation scenario. These projections are graphically displayed in Figure 10. The total controller requirements are also shown in this figure. The CAR model actually uses three position staffing requirements in the formulation of a hiring decision. These requirements are (1) the required number of controllers qualified to man R positions, (2) the required number of controllers qualified to man R positions or D and T positions, and (3) the required number of controllers qualified to man R positions, D and T positions, or A positions. The cumulative nature of these requirements is due to the fact that control positions can be manned by controllers who are qualified at a higher level (for example, an A position can be manned by an R-man, a D-man, or an A-man). The requirement shown in Figure 10 is the total

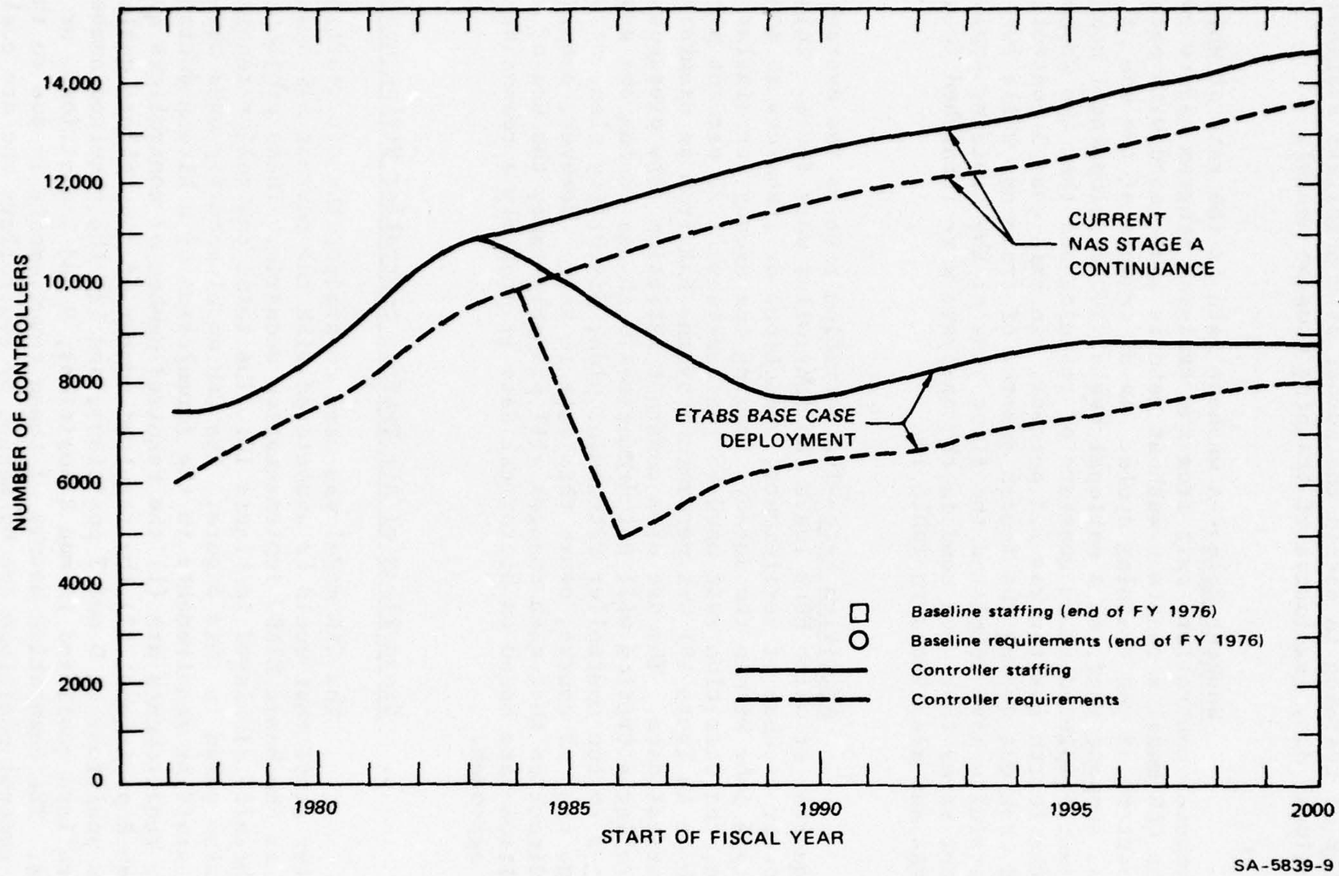

FIGURE 10 CONTROLLER REQUIREMENTS AND STAFFING

controller requirement. For the current NAS Stage A system the total controller staff is projected to rapidly increase (at an average rate of about 750 controllers per year) to a controller staff of about 11,000 at the beginning of FY 1983. From then the increase is projected to continue at a much more moderate rate of about 225 controllers per year. The tapering of this curve is due to the fact that individual ARTCCs have reached their maximum sectorization and staffing levels. Notice that this projection has the same general shape as the projection of total controller requirements. The difference between these two curves (usually between 750 to 1,500 controllers at any given time) is due to the training requirements (that is, some controllers are not even qualified as A-men and the partially qualified developmental controllers are not 100 percent available).

The staffing projection for the base case ETABS implementation scenario is significantly different from that of the current system for the period beyond the end of FY 1982. This projection is based on the assumption that the actual hiring of new controllers will be reduced in advance of ETABS implementation in anticipation of reduced controller staffing requirements. In fact, in this implementation scenario no new controllers have to be hired from the second quarter of FY 1983 until the third quarter of FY 1990, as indicated in Figure 11. Beginning in FY 1983 the size of the total en route controller work force is projected to rapidly decrease from about 11,000 persons to about 8,000 persons in FY 1990. This sharp decrease is solely due to controller attrition and developmental washout. The ETABS staffing decrease precedes the requirements decrease by one year because of the removal of A-controller training requirements. The CAR analysis found that A-position manning will be the critical advance recruitment parameter during the mid-1980s for the current NAS Stage A system. Recall the A-position qualification time is one year (Table 20), and removal of A-position requirements by ETABS enables an early reduction in hiring. The difference between the ETABS staffing and requirements projections for FY 1983 through FY 1990 is due not only to training requirements but also to a surplus of controllers.

In comparing the controller staffing projection of the current NAS Stage A system to that of ETABS, ETABS shows the potential for a significant reduction of the projected controller staff. The controller staff, including advance recruitment, projected for the current system at the end of 1999 is 14,740 controllers (3,252 developmentals, 11,488 FPLs). In contrast, the base case ETABS implementation scenario is projected to have only 8,969 controllers at the end of 1999 (1,600 developmentals, 7,369 FPLs). Over the entire study period, the current NAS Stage A system is projected to require 274,000 controller man-years of effort (73,000 developmental man-years, 201,000 FPL man-years). For the same period, the base case ETABS implementation scenario would require only 205,000 controller man-years (43,000 developmental man-years, 162,000 FPL man-years).

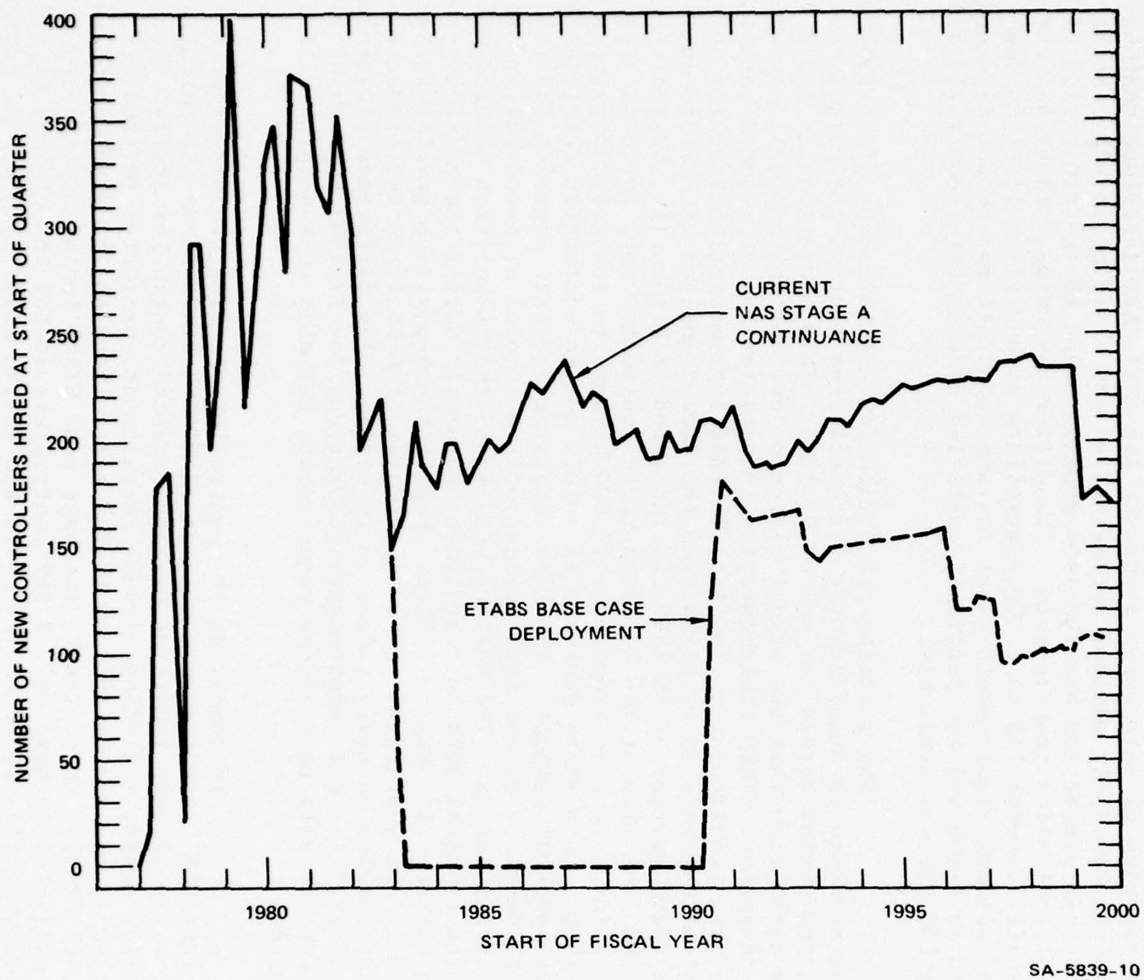

FIGURE 11 CONTROLLER QUARTERLY HIRING RATE

The projected savings of 69,000 controller man-years over the study period must be viewed with some caution due to some of the assumptions on which the base case ETABS implementation scenario is based. One of the assumptions that may be viewed with some skepticism is that there is no constraint on the rate of reduction of the number of en route sectors. As shown in Figure 12, the base case ETABS implementation scenario reduces the number of en route sectors by almost 25 percent over the initial two-year ETABS deployment period. A sector reduction of this magnitude over a 2-year period may not be practical nor desirable due to the amount of effort involved in resectorization, changes in procedures, charting, software adaptation, and the like. Accordingly, this factor is included in the sensitivity analysis presented in Section VI.

2. Administrative Management and Operational Support Staff

The projections of AAT administrative management and operations support staff, which are shown in Figure 13, are based exclusively on the application of the FAA's Air Traffic Control Staffing Standard System.[8] The staffing standards were used to develop projections of the number of persons in each of the following job categories:

Team supervisor
Facility chief
Deputy chief
Secretary (chief/deputy chief)
Assistant chief
Data systems officer
Flight data monitor
Card punch operator
Data systems specialist
Military liaison officer
Military liaison specialist
Evaluation and proficiency development officer
Personnel management specialist
Administrative and/or personnel assistant
Management specialist assistant
Flow controller
Evaluation and proficiency development specialist (EPDS)
Area officer
Area specialist
Cartographer
Teletype supervisor
Teletype operator
Clerk

No projection was made for the job category of Area Coordinator, since this is a nonstandard requirement.

In the case of the team supervisor job category, the staffing standard requirement is based on the peak shift position manning

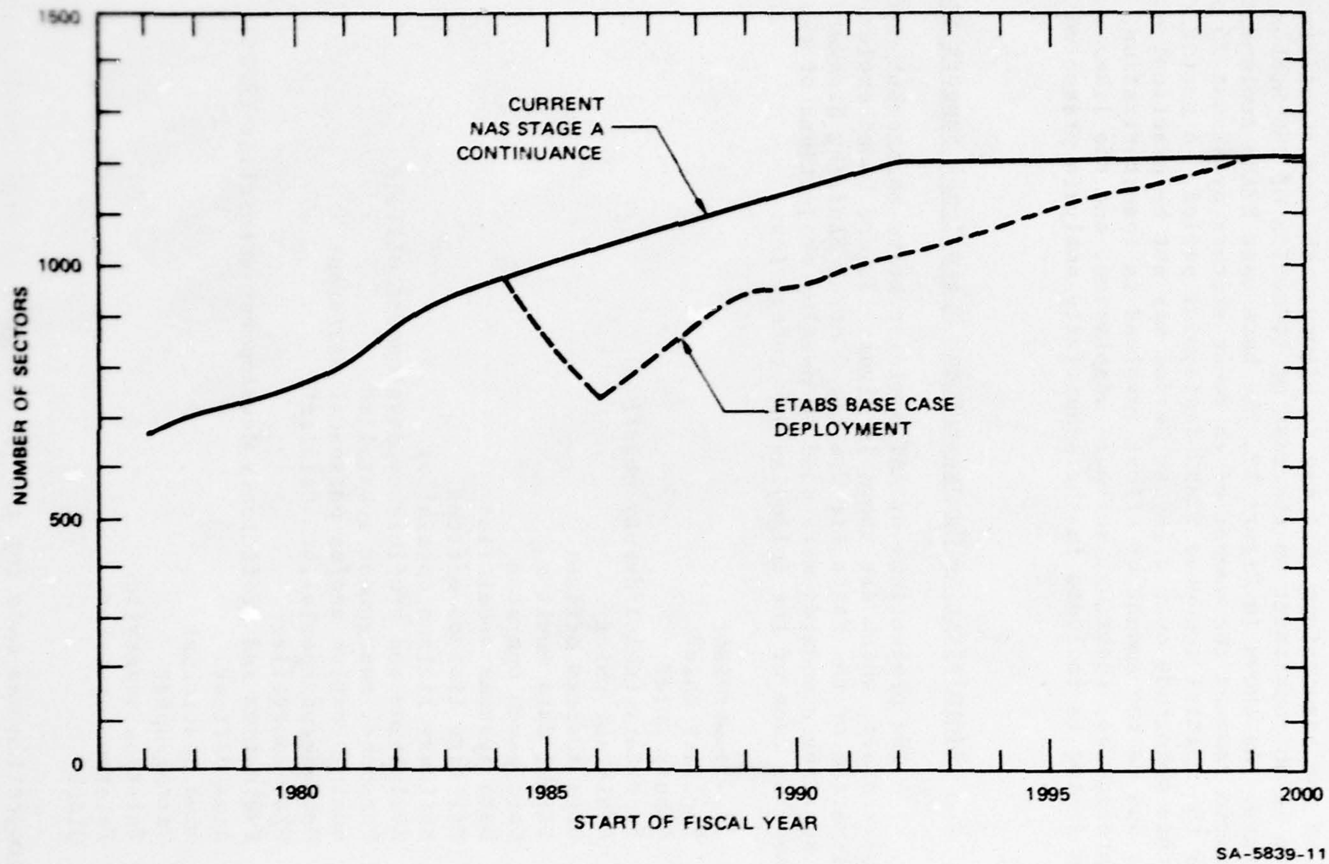

FIGURE 12 SECTOR REQUIREMENTS

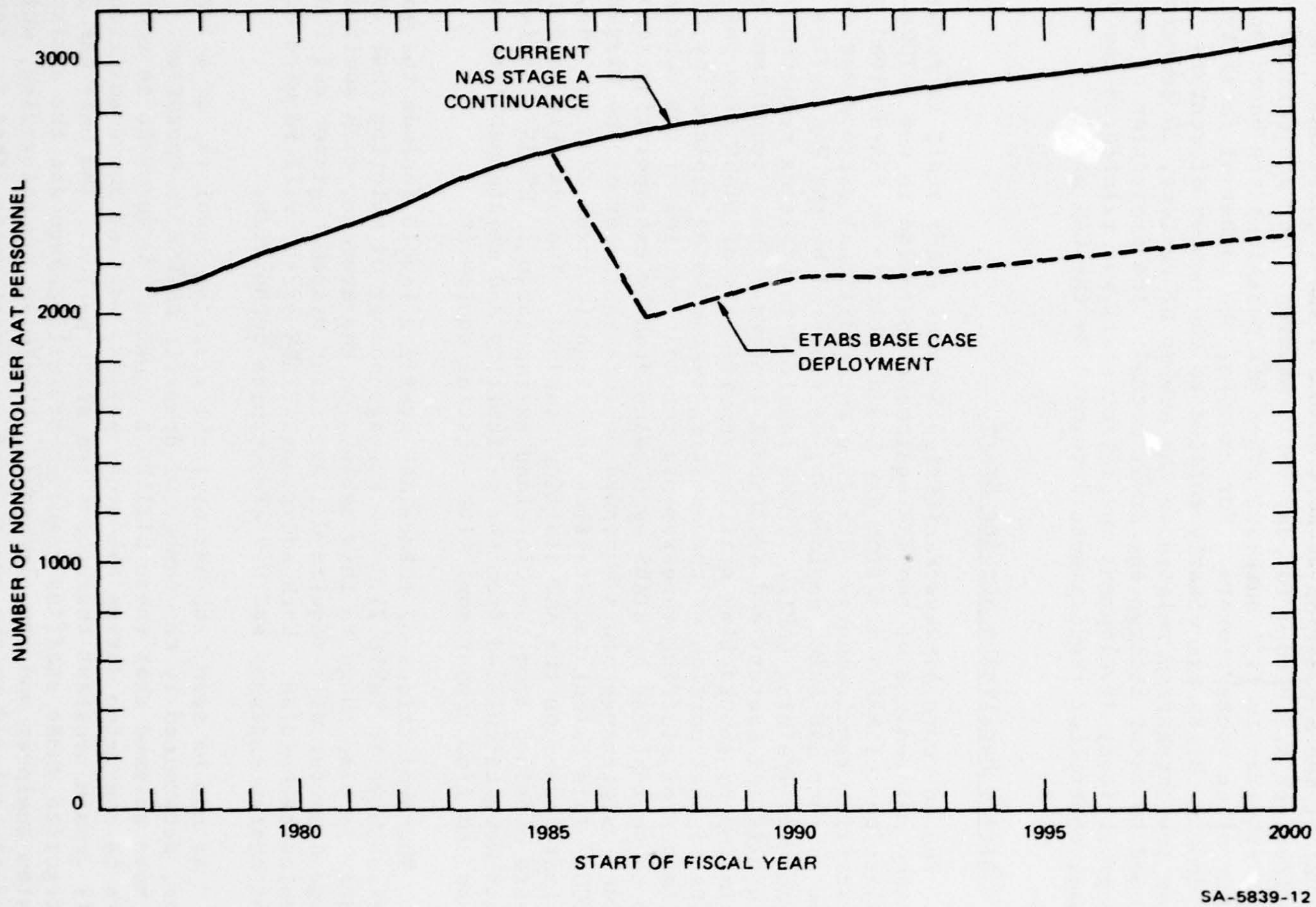

FIGURE 13 NONCONTROLLER AIR TRAFFIC SERVICE STAFFING

requirements. In this case the annual controller staffing requirements developed by the CAR model were used after being multiplied by a day-shift manning factor based on Table 13 data. Table 13 shows that 28 percent of the R position as well as the D and T positions' annual staffing requirements are needed for day-shift manning. Our projections of the staff required to fill numerous other AAT positions are based on the number of en route centers. For example, the number of facility chiefs and deputy chiefs are clearly related to the number of centers. For those job categories related to the number of centers, 20 centers are assumed to exist through the study period. The projection of evaluation and proficiency development specialist staff was related to the projected annual controller requirements developed by the CAR model.

C. Airway Facilities Service Staff

The en route Airways Facilities Service (AAF) staff is responsible for the maintenance of the FAA equipment installed in the ARTCCs. The projections of AAF's staffing are based entirely on FAA-derived estimates of staffing requirements. Staffing for additional sectors was derived from current AAF ARTCC employment, as reported by the FAA Office of Personnel and Training (APT). ETABS resulted in staffing reductions for both existing sectors and additional sectors. These reductions were estimated by subtracting staffing requirements of ETABS from the requirements of that portion of the existing system being replaced by ETABS. Estimates of staffing requirements for that portion of the current system to be replaced by ETABS were calculated by extrapolating reported actual maintenance hours expended on this equipment at the Cleveland ARTCC. This calculated staffing was slightly lower than an independent estimate based on the AAF staffing standard. The analysis used the lower figure obtained from the Cleveland extrapolation. ETABS staffing requirements were calculated from the reliability and maintainability specifications and from comparisons with existing equipment.

The projections of future AAF staffing levels include the job categories shown in Table 21. The average number of existing positions per center is also shown in this table. On the average, each additional NAS Stage A sector will require 0.1 assistant system engineer and 1.0 electronics technician. Each additional ETABS sector will require 0.1 assistant system engineer and 0.9 electronics technician.

As can be seen, the AAF national staffing level is, to a large degree, determined by the number of domestic ARTCCs in operation. Since we have assumed that there will be a constant 20 domestic en route centers in operation during the study period, most of these positions also will remain constant throughout the study period. The only AAF job categories whose staffing requirements will change are the assistant system engineer and the electronic technician job categories, which are directly related to the quantity of equipment units (that is, sectors) required and are thus indirectly related to traffic activity.

Table 21

ESTIMATED AAF STAFFING

Job Category	Average Number of Persons per Center
Sector manager	1
Assistant sector manager	1
System engineer	5
Assistant system engineer	5
Crew chief	10
Systems performance officer	1
Proficiency development and evaluation officer	1
Environmental support supervisor	1
System performance specialist	5
Electronics technician	59
Environmental support technician	10
Logistic specialist/clerk	2
Plant maintainer	7-1/2
Trainee electronics technician	3
Computer operator	6
Secretary	1
Clerk/stenographer/typist/card punch operator	1-1/2
Administrative officer/assistant	1
Total	121

Source: FAA

The projections of AAF staffing for the current system and for the basic ETABS implementation scenario are shown in Figure 14.

The primary reason the ETABS deployment reduces AAF staff requirements is the reduction of the number of additional sectors. A secondary cause of this reduction is the smaller average number of electronics technicians required to maintain each ETABS sector. The reason for this reduced electronic technician staffing requirement is the elimination of the mechanical strip printers that have experienced an exceptionally high failure rate. This secondary reduction in staffing does not occur until two years after ETABS has been fully deployed.

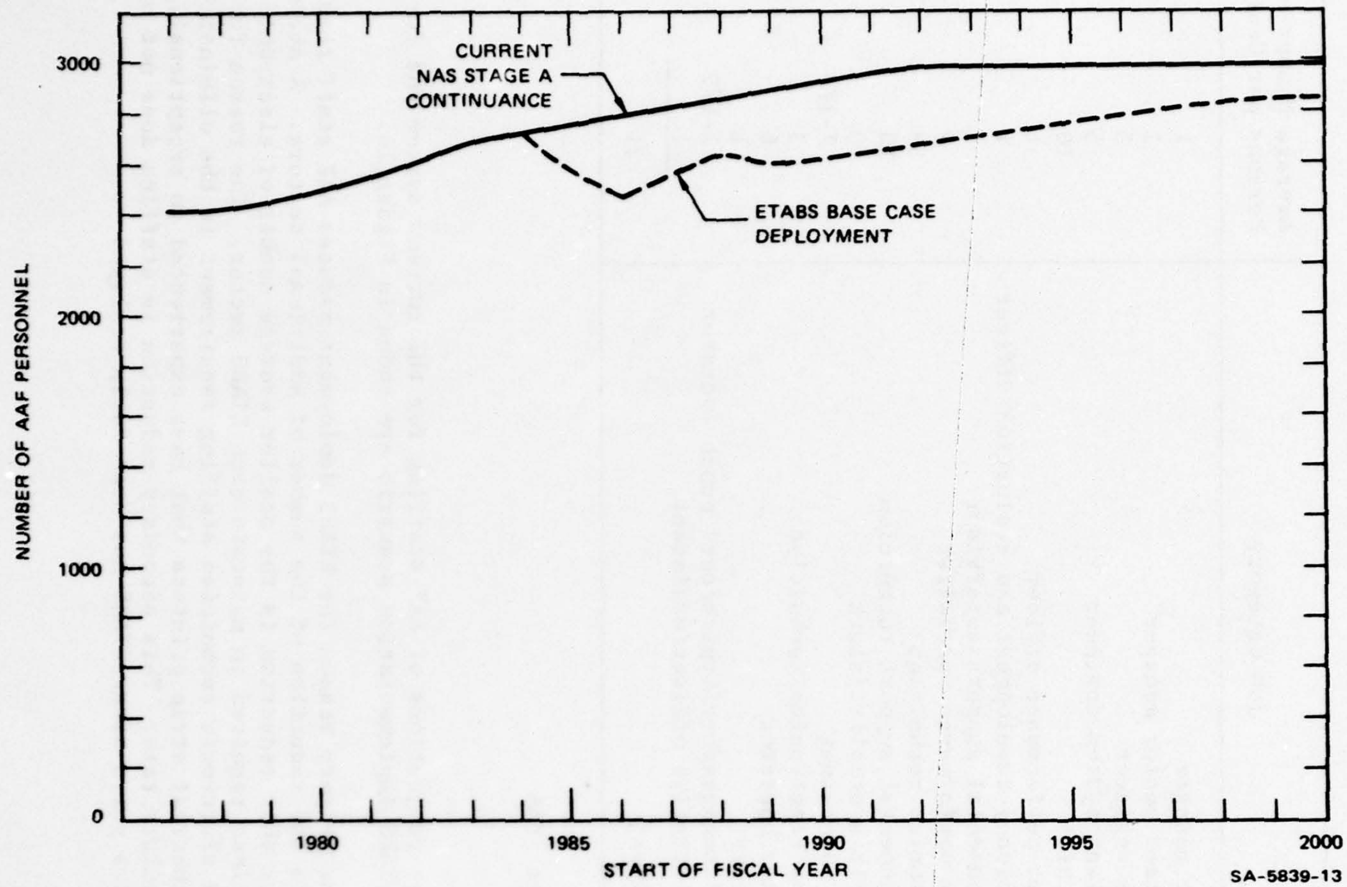

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FIGURE 14 AIRWAY FACILITIES SERVICE STAFFING

D. Total Staffing Projections

The annual numbers of controllers, other AAT, and AAF staff are listed in Tables 22 and 23 for current NAS Stage A continuance and base case ETABS deployment. These data summarize the analyses and results discussed previously in this section.

Table 22

20-CENTER STAFFING ESTIMATES FOR CURRENT NAS STAGE A CONTINUANCE

Fiscal Year	Number of Persons at Year End					
	Controller Staff			Other AAT Staff	AAF Staff	Total
	Developmental	FPL	Subtotal			
1976	2,337*	5,131*	7,468*	2,102†	2,420‡	11,990
1977	2,329	5,177	7,506	2,138	2,423	12,067
1978	2,245	5,710	7,955	2,232	2,451	12,638
1979	2,808	5,888	8,696	2,279	2,486	13,461
1980	3,423	6,174	9,597	2,349	2,526	14,472
1981	4,283	6,197	10,480	2,413	2,609	15,502
1982	4,335	6,574	10,909	2,512	2,681	16,102
1983	3,921	7,192	11,113	2,597	2,717	16,427
1984	3,407	7,948	11,355	2,636	2,759	16,750
1985	2,922	8,683	11,605	2,684	2,790	17,079
1986	2,918	9,030	11,948	2,714	2,820	17,482
1987	3,095	9,184	12,279	2,752	2,858	17,889
1988	3,141	9,373	12,514	2,783	2,891	18,188
1989	3,123	9,584	12,707	2,822	2,919	18,448
1990	3,069	9,857	12,926	2,845	2,947	18,718
1991	2,994	10,122	13,116	2,869	2,971	18,956
1992	2,951	10,321	13,272	2,900	2,971	19,143
1993	2,981	10,484	13,465	2,916	2,971	19,352
1994	3,036	10,664	13,700	2,939	2,971	19,610
1995	3,127	10,819	13,946	2,963	2,971	19,880
1996	3,238	10,946	14,184	2,987	2,971	20,142
1997	3,331	11,107	14,438	3,011	2,971	20,420
1998	3,399	11,289	14,688	3,041	2,971	20,700
1999	3,252	11,488	14,740	3,073	2,971	20,784

*Actual on-board 1976 baseline controller staff reported by FAA.[7]

†Calculated required 1976 baseline support staff reported by FAA.[7]

‡Estimated required 1976 baseline maintenance staff calculated by CAR model.

Table 23

20-CENTER STAFFING ESTIMATES FOR BASE CASE ETABS DEPLOYMENT

Fiscal Year	Number of Persons at Year End					
	Controller Staff			Other AAT Staff	AAF Staff	Total
	Developmental	FPL	Subtotal			
1976	2,337*	5,131*	7,468*	2,102†	2,420‡	11,990
1977	2,329	5,177	7,506	2,138	2,423	12,067
1978	2,245	5,710	7,955	2,232	2,451	12,638
1979	2,808	5,888	8,696	2,279	2,486	13,461
1980	3,423	6,174	9,597	2,349	2,526	14,472
1981	4,283	6,197	10,480	2,413	2,609	15,502
1982	4,335	6,574	10,909	2,512	2,681	16,102
1983	3,367	7,192	10,559	2,597	2,717	15,873
1984	2,135	7,948	10,083	2,636	2,575	15,294
1985	929	8,683	9,612	2,305	2,465	14,382
1986	124	9,030	9,154	1,978	2,539	13,671
1987	0	8,713	3,713	2,026	2,629	13,368
1988	0	8,292	8,292	2,089	2,592	12,973
1989	0	7,892	7,892	2,130	2,616	12,638
1990	306	7,510	7,818	2,144	2,640	12,602
1991	941	7,148	8,089	2,157	2,668	12,914
1992	1,510	6,802	8,312	2,177	2,694	13,183
1993	2,035	6,472	8,507	2,198	2,724	13,429
1994	2,294	6,419	8,713	2,219	2,753	13,685
1995	2,263	6,661	8,924	2,240	2,781	13,945
1996	2,135	6,859	8,994	2,253	2,808	14,055
1997	1,941	8,024	8,965	2,274	2,837	14,076
1998	1,767	7,194	8,961	2,294	2,851	14,106
1999	1,600	7,369	8,969	2,308	2,851	14,128

*Actual on-board 1976 baseline controller staff reported by FAA.[7]

†Calculated required 1976 baseline support staff reported by FAA.[7]

‡Estimated required 1976 baseline maintenance staff calculated by CAR model.

V ANALYSIS OF BASE CASE ETABS COSTS AND SAVINGS

This section documents the examination of the costs associated with the base case ETABS implementation scenario as well as the costs associated with the continuance of the current ATC system throughout the study period. In this analysis, the major elements of FAA expenditures were projected for both the current NAS Stage A system and ETABS. These cost elements included:

- FAA staffing costs
- FAA engineering and development costs
- FAA facilities and equipment costs
- FAA maintenance costs
- FAA training costs.

The FAA's annual expenditures during the FY 1977-99 period are projected for the NAS Stage A system with and without ETABS. For both situations, these projections were originally made in terms of 1976 constant dollars and assumed that neither system had any residual value at the end of the analysis period. The present value (start of FY 1976) of the projected annual expenditures associated with each cost element was then computed, assuming end-of-year lump sum expenditures. In accordance with U.S. Office of Management and Budget policy for federal government engineering economy studies, a 10-percent discount rate was used. The projected discounted cash flows for the current ATC system and the basic ETABS implementation scenario were then used to determine the potential cost savings associated with ETABS.

The economic analysis did not investigate certain other economic and social factors and consequences that may be associated with the operation of either the current NAS Stage A system or ETABS. These included factors, such as aircraft delay, safety, and the like, whose analyses are beyond the scope of this project. However, our analyses have indicated that, at worst, the introduction of ETABS will have a neutral effect on the factors of delay and safety, and most probably will have a significantly positive effect.

A. FAA Staffing Costs

Staffing costs, the major expenditure associated with either system, account for over 90 percent of the total costs for each system. Considering the staffing projections detailed in Section IV, it is not surprising that controller costs are the principal element of the staffing costs. The determination of the controller costs used the controller staffing

projections and FAA-supplied information about the average annual wage cost for developmental ($16,800 per year) and FPL ($31,900 per year) controllers. Using these figures, the estimates of the controller staffing discounted costs for the current system will be $2,362 million dollars whereas the ETABS controller staffing costs are estimated to be $2,033 million dollars. The discounted cost savings during the study period due to ETABS is therefore estimated to be $329 million dollars.

The annual staffing cost for AAT staff, other than controllers, is shown in Table 24. These cost figures were provided by the FAA and include benefits and premium pay.* For the NAS Stage A system, the administrative management and operational support costs during the FY 1977-99 period are projected to be 636 million discounted dollars. The analogous cost for the basic ETABS implementation scenario is projected to be 560 million discounted dollars. The savings through FY 1999 due to the implementation of ETABS is estimated to be 76 million discounted dollars.

The final element of the projections of staffing costs is the AAF staff. The annual average cost, including benefits and premium pay, for each of the AAF job categories is shown in Table 25. The AAF staffing cost for the current system over the FY 1977-99 period is projected to be 555 million discounted dollars. For ETABS, the costs are projected to be 531 million discounted dollars. The savings due to ETABS is therefore estimated to be 24 million discounted dollars.

The study period discounted staffing costs for both systems are summarized in Tables 26 and 27.

B. FAA Engineering and Development (E&D) Costs

The estimated engineering and development costs associated with ETABS are shown in Table 28. These cost estimates include contract costs, FAA Washington in-house costs, and FAA NAFEC in-house costs for the procurement, test, and evaluation of an ETABS engineering model at NAFEC. There are no comparable E&D costs for the current system.

C. Facilities and Equipment (F&E) Costs

The F&E cost estimates for the basic ETABS implementation scenario are based on an initial purchase of 1,000 sector units. Of these, 50 will be distributed between NAFEC and the FAA academy, 80 will be used

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*It should be noted that in 1977 the average annual cost for a full performance level controller, deputy chief, assistant chief, evaluation and proficiency development officer, data systems officer, data systems specialist, area officer, and team supervisor would be somewhat higher than that used in the cost analysis because of the higher GS grade levels being put into effect at the busier ARTCCs.

Table 24

AIR TRAFFIC SERVICE STAFFING COSTS
(En Route)

Title	Average Annual Wage Cost* ($)
Team supervisor	$36,900
Facility chief	41,400
Deputy chief	36,900
Secretary to chief	11,400
Assistant chief	36,900
Data system officer	36,900
Flight data monitor	14,400
Card punch operator	8,500
Data system specialist	31,200
Military liaison officer	36,900
Military liaison specialist	31,200
Evaluation and proficiency development officer	36,900
Personnel management specialist	20,900
Administrative assistant	14,100
Personnel management specialist assistant	14,100
Flow controller	36,900
Evaluation and proficiency development specialist	31,200
Area officer	36,900
Area specialist	31,200
Cartographer	14,100
Supervisory teletypist	13,300
Teletypist	11,600
Clerk	10,200

*Annual costs include salary, benefits, and premium pay.

Table 25

AIRWAY FACILITIES SERVICE STAFFING COSTS
(En Route)

Title	Average Annual Wage Costs* ($)
Sector manager	$40,140
Assistant sector manager	35,160
System engineer	36,900
Assistant system engineer	33,120
Crew chief	32,170
Systems performance officer	29,750
Proficiency development and evaluation officer	30,620
Environmental support supervisor	25,020
System performance specialist	30,560
Electronics technician	26,050
Environmental support technician	20,610
Logistic specialist/clerk	14,610
Plant maintainer	16,470
Trainee electronics technician	12,280
Computer operator	17,770
Secretary	12,310
Clerk/stenographer/typist/card punch operator	9,950
Administrative officer/assistant	13,550

*Annual costs include salary, benefits, and premium pay.

Table 26

20-CENTER STAFFING COST ESTIMATES FOR CURRENT NAS STAGE A CONTINUANCE

Fiscal Year	Present Value Annual Staffing Cost (millions of 1976 dollars)					
	Controller Staff			Other AAT Staff	AAF Staff	Total*
	Developmental	FPL	Subtotal*			
1977	$ 31.6	$ 135.2	$ 166.8	$ 52.9	$ 50.7	$ 270.4
1978	28.9	130.2	159.1	50.6	46.7	256.4
1979	30.6	125.8	156.5	47.2	43.1	246.7
1980	33.8	119.2	152.9	44.4	39.8	237.2
1981	38.4	110.1	148.5	41.7	37.5	227.6
1982	37.9	104.4	142.3	39.7	35.0	217.1
1983	31.6	103.9	135.5	37.5	32.3	205.4
1984	25.7	103.6	129.3	34.7	29.8	193.9
1985	20.0	103.5	123.6	32.2	27.4	183.2
1986	17.0	99.8	116.8	29.6	25.2	171.7
1987	16.4	92.6	108.9	27.4	23.3	159.6
1988	15.2	86.0	101.2	25.2	21.4	147.8
1989	13.8	79.8	93.7	23.3	19.7	136.6
1990	12.4	74.5	86.9	21.4	18.0	126.3
1991	11.1	69.6	80.7	19.6	16.5	116.8
1992	9.8	64.7	74.5	18.0	15.0	107.6
1993	9.0	59.8	68.8	16.5	13.7	98.9
1994	8.3	55.3	63.5	15.1	12.4	91.1
1995	7.7	51.0	58.8	13.9	11.3	84.0
1996	7.3	47.0	54.2	12.7	10.3	77.3
1997	6.8	43.3	50.1	11.7	9.3	71.1
1998	6.3	40.0	46.3	10.8	8.5	65.6
1999	5.7	37.0	42.6	9.9	7.7	60.3
Total*	$425.3	$1,936.2	$2,361.5	$636.0	$554.8	$3,552.3

*Summation differences from total indicated are due to round off.

Table 27

20-CENTER STAFFING COST ESTIMATES FOR BASE CASE ETABS DEPLOYMENT

Fiscal Year	Present Value Annual Staffing Cost (millions of 1976 dollars)					
	Controller Staff			Other ATT Staff	AAF Staff	Total*
	Developmental	FPL	Subtotal*			
1977	$ 31.6	$ 135.2	$ 166.8	$ 52.9	$ 50.7	$ 270.4
1978	28.9	130.2	159.1	50.6	46.7	256.4
1979	30.6	125.8	156.5	47.2	43.1	246.7
1980	33.8	119.2	152.9	44.4	39.8	237.2
1981	38.4	110.1	148.5	41.7	37.5	227.6
1982	37.9	104.4	142.3	39.7	35.0	217.1
1983	29.5	103.9	133.4	37.5	32.3	203.2
1984	18.5	103.6	122.2	34.7	27.8	184.6
1985	8.9	103.5	112.4	27.1	24.1	163.6
1986	2.3	99.8	102.1	20.6	22.6	145.4
1987	0.0	90.2	90.2	19.3	21.3	130.8
1988	0.0	78.1	78.1	18.2	19.1	115.4
1989	0.0	67.5	67.5	17.0	17.5	102.0
1990	0.4	58.4	58.9	15.5	16.1	90.5
1991	2.6	50.6	53.2	14.2	14.8	82.2
1992	4.4	43.7	48.1	13.1	13.6	74.8
1993	5.6	37.8	43.4	12.0	12.5	67.9
1994	6.2	33.2	39.4	11.1	11.5	62.0
1995	5.7	31.2	36.8	10.2	10.6	57.6
1996	4.9	29.3	34.2	9.3	9.7	53.2
1997	4.2	27.3	31.4	8.6	8.9	48.9
1998	3.4	25.4	28.8	7.9	8.1	44.9
1999	2.8	23.7	26.5	7.2	7.4	41.1
Total*	$300.6	$1,732.2	$2,032.8	$559.9	$530.7	$3,123.4

*Summation difference from totals indicated are due to round off.

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COST ANALYSIS OF ELECTRONIC TABULAR DISPLAY SUBSYSTEM. (U)

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Table 28

ENGINEERING AND DEVELOPMENT COST ESTIMATES

Fiscal Year	Cost (thousands of dollars)	Present Value Costs (thousands of 1976 dollars)
1978	$1,890	$1,420
1979	1,450	990
1980	900	559
Total	$4,240	$2,969

Source: SRDS, FAA

as spares at ARTCC facilities, 20 will be used at center supervisory positions, 80 will be used for DYSIM training activities, and the remaining 770 units will be used at operational sectors. The cost of the initial purchase is spread over 4 years, from FY 1982 to FY 1985. The F&E expenditures required for this initial purchase are shown in Table 29. These cost estimates account for hardware procurement, software procurement, site preparation, installation, and testing of the first 1,000 ETABS sector units. Beyond the initial procurement for 1,000 sectors, the procurement and installation costs for each additional sector with ETABS

Table 29

ETABS INITIAL F&E COSTS
(1,000 Sector Units)

Fiscal Year	Cost (thousands of dollars)	Present Value Costs (thousands of 1976 dollars)
1982	$ 7,250	$ 3,720
1983	8,250	3,349
1984	10,250	4,347
1985	10,250	3,952
Total	$36,000	$15,368

Source: SRDS and AAF, FAA

are \$207,300.* These costs for each additional current NAS Stage A system sector (including an A position) are \$239,100.*

The total F&E costs during the study period are related to the projected growth rate of en route sectors for both the current system and the base case ETABS implementation scenario. The procurement and installation of additional NAS Stage A sectors for the current system will cost \$63 million during the study period. The total F&E costs for the base case ETABS deployment is projected to be \$82 million.

D. FAA Maintenance Costs

Table 30 details FAA estimates of the annual maintenance and operations costs for an additional sector using the current NAS Stage A system and for an additional sector using ETABS. The annual maintenance and operations costs (exclusive of wage costs) for an ETABS sector will be lower than for an existing sector, primarily because of reduced requirements for telephone key equipment. (Cost savings due to reduced maintenance staffing requirements have been previously discussed.) Telephone key equipment reductions result from the elimination of the A position. At present, some centers use one A-position telephone equipment set per

Table 30

SECTOR MAINTENANCE AND OPERATIONS COSTS

Cost Element	Cost per Sector (\$)†	
	NAS Stage A†	ETABS
Spare parts and supplies	\$ 7,617	\$ 7,617
Key equipment (TELCO)	10,476	8,730
Leased lines	9,952	9,952
Electric power	500	650
Administrative telephone	500	500
Janitorial service	1,000	1,000
Total	\$30,045	\$28,449

†Derived from data obtained from AAF and Regional Offices, FAA

*Costs derived by SRDS from data supplied by ARD, AAF, and AAT.

sector while other centers use one A-position telephone equipment set for every two sectors. A conservative reduction in key equipment costs of one-sixth the NAS Stage A costs is estimated for ETABS. Table 30 figures show that ETABS has an annual cost advantage of $1,600 per sector. However, the base case implementation plan has assumed that ETABS does not reduce the sector maintenance costs until two years after the transition to ETABS has been completed. Until this time both the flight strip printers and the ETABS displays must be maintained in operational readiness. Using the FAA cost estimates, the total maintenance and operations costs during the study period for the current system will be 231 million discounted dollars. For the base case ETABS implementation scenario the costs would be 209 million discounted dollars, a savings of 22 million discounted dollars.

E. FAA Training Costs

It is expected that the implementation of ETABS will affect the training costs for both AAT and AAF personnel.

1. AAT Training Costs*

The following paragraphs give the estimated costs associated with training AAT personnel, as used in the analyses. These cost estimates were developed by SRDS, based on data supplied by APT and AAT.

a. Estimated Cost of Providing an ETABS ATC Training Course

The estimated cost for training an FAA Academy instructor on ETABS and for subsequent course development by the FAA Academy instructors is $9,186. Included in this estimate are the costs for tuition, materials, FAA Academy instructor/course developer and clerical salaries, travel, and per diem.

b. Estimated Cost of ETABS ATC Operational Training for Controllers on Board During the Transition Period

The estimated cost of providing ETABS ATC operational training to en route controllers on board during the transition period from paper flight strips to ETABS is $18,188. The training would be accomplished by having FAA Academy instructors travel to each of the 20 centers to conduct two 16-hour courses of training. (Approximately

*Source: SRDS, FAA.

40 personnel could be trained at each center.) These trained personnel would then conduct the same course for the remaining ARTCC facility personnel using lesson plans provided by the FAA Academy. This method of training, previously used by the FAA, does not require a large cost outlay, since most of the training is conducted by facility instructors already on site. Included in this estimate ($18,188) are the costs for FAA Academy instructor salaries, travel, and per diem.

c. Estimated Cost of Providing an ETABS Data System Specialist (DSS) Training Course

The estimated cost for FAA Academy instructor training on ETABS software and for subsequent course development by the FAA Academy instructors is $46,977. Included in this estimate are costs for tuition, materials, FAA Academy instructor/course developer and clerical salaries, travel, and per diem.

d. Estimated Cost of ETABS DSS Training for DSS Personnel on Board During the Transition Period

The estimated cost of providing ETABS software training to DSS personnel on board during the transition period from paper flight strips to ETABS is $114,625. This training would be accomplished by having DSS personnel at the ARTCCs and at NAFEC travel to the FAA Academy for a 100-hour training course. Included in this estimate ($114,625) are costs for FAA Academy instructor and clerical salaries, student travel, and per diem.

e. Estimated Cost of Initial Controller Training

In addition to the ETABS training that would be required for AAT personnel on board during the transition period from paper flight strips to ETABS, there are training costs associated with the required initial training for new hires at the FAA Academy. The FAA's Technical Training Branch (APT-310) estimated that little or no additional training costs would be incurred for an ETABS initial training course compared to the present initial training course. This is due to the fact that initial ETABS training would replace the initial training for the current system without a major modification of the training schedule. Therefore, these initial training costs were not included in the analyses under the assumption that these costs remain constant irrespective of the ATC system design. However, the student travel and per diem costs associated with FAA Academy training were estimated at $2,400 per new hire. The total initial training costs would thus be reduced if the number of new hires is reduced.

2. Airways Facilities Training Costs

The cost estimates for AAT training are categorized as course development costs, initial retraining costs, and attrition and refresher training costs. The estimates of AAF training costs used in developing our cost projections for training are shown below. These cost estimates are based on information obtained from the FAA.

a. Cost of ETABS AAF Training Course Development

The cost of developing courses for initial retraining, attrition training, and refresher training is estimated at $100,000. Included in this estimate are costs of FAA Academy staff salaries, travel, and per diem.

b. Cost of Initial ETABS Retraining for AAF Personnel

AAF personnel are now maintaining the present system. The cost of retraining technicians working in the present system is estimated at $725,100, including all training facility costs plus student travel and per diem.

For the purpose of our analyses, the costs given in paragraphs a and b above were combined and the expenditures allocated to three fiscal years as follows:

Fiscal Year	ETABS One-Time Course Development and Initial Training Costs ($)
1983	$ 72,500
1984	376,300
1985	376,300

c. Cost of Attrition Training

Training of personnel replacing those lost by promotion, retirement, relocation, and separation is estimated to cost $84 per year per sector for the current system and $175 per year per sector for the ETABS system. These costs include all training facility costs plus student travel and per diem.

d. Cost of Refresher Training for AAF Personnel

Maintenance of skill levels may require refresher training each four to five years. The cost of this training is estimated at $53 per year per sector for ETABS, including all training facility costs plus

student travel and per diem. This cost may not actually be incurred because formal (academy) refresher training programs are not now in existence. However, to be conservative the cost was included in the analysis.

3. Projections of FAA Training Expenditures

Using the estimates of the AAT and AAF training, costs projections of FAA expenditures for training during the study period were developed. These are projected to be $17,715,000 for the current NAS Stage A system and $12,773,000 for the ETABS base case implementation scenario.

F. Summary of ETABS and NAS Stage A System Costs and Savings

The estimates of the total present value costs for the NAS Stage A system and base case ETABS during the study period are shown in Table 31. If the present system is continued throughout the study period, it is projected that the total FAA costs will exceed 3.8 billion discounted dollars. The development and deployment of ETABS in accordance with the base case implementation scenario is projected to reduce FAA costs by 434 million discounted dollars.

Table 31

COSTS COMPARISONS: BASE CASE

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,361,544	$2,032,817	$328,727
Other AAT staff	636,023	559,902	76,121
AAF staff	554,767	530,680	24,087
E&D costs	0	2,969	-2,969
F&E costs	63,136	82,255	-19,119
Maintenance	230,903	209,024	21,879
Training	17,715	12,773	4,942
Total	$3,864,088	$3,430,420	$433,668

VI SENSITIVITY ANALYSES OF COSTS AND SAVINGS

Sections IV and V of this report documented our projections of the staffing and costs associated with the current NAS Stage A system and the base case ETABS implementation scenario for the FY 1977-99 period. These sections also documented the major assumptions made in the analyses of these two systems. In these analyses, some such assumption had to be made because of the many uncertainties entailed in developing projections of the future ATC operational environment. This section examines the sensitivity of the results of the base case analyses to changes in these assumptions. The main objectives of these sensitivity analyses are to determine the relative importance of these assumptions in the analyses and to assess the extent to which changes in these assumptions can affect the results. The examination of sensitivity used the analyses reported in Sections IV and V. These analyses show that the development and deployment of ETABS according to a base case implementation scenario would result in a significant cost savings to the FAA compared to the current system. The sensitivity analyses documented in this section were performed by varying one factor or assumption of this base case while holding constant all of the other basic factors or assumptions. Recall that the base case assumes the smoothed traffic projection profile.

A. Transition to ETABS Sectorization

The base case analysis assumes that the number of operational sectors can be reduced at the same rate as the sector requirements are reduced through the deployment of ETABS. It was originally felt that this was a realistic assumption for future planning purposes and that it would also simplify the analysis efforts. However, in the basic ETABS implementation scenario the number of en route sectors is reduced by over 200 sectors during the initial 2-year ETABS deployment period. The effects of constraining the rate of sector reduction are examined in the event such a large reduction, almost 25 percent, is not practical or desirable within a 2-year period.

1. Ten-percent Sector Reduction Allowed

This analysis examined the effect on cost and staffing projections of allowing the number of sectors to be reduced by no more than 10 percent per year. This maximum 10-percent reduction in sectors was allowed only during the 2-year deployment period and only for those sectors where ETABS was being installed during the year. For example, during the first years of ETABS deployment if 500 of 1000 NAS Stage A sectors were converted to ETABS, the minimum number of sectors required

would be 950 [that is, 500 NAS Stage A sectors plus 500 x (1.00 - 0.10) or 450 ETABS sectors]. The projection of sector growth and decline under this assumption is shown in Figure 15. The breakdown of the costs and savings associated with this transition from current NAS Stage A sectors to ETABS sectors is shown in Table 32. Notice that the staffing costs for air traffic controllers is the same in this situation as for the base case. This occurs because the reduction in sectors is still more rapid than the reduction in controllers through attrition, thus no additional controllers beyond those hired in the base case are needed in this scenario.

Table 32

COSTS COMPARISONS: 10 PERCENT SECTOR REDUCTION

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,361,544	$2,032,817	$328,727
Other AAT staff	636,023	565,601	70,422
AAF staff	554,767	534,444	20,323
E&D costs	0	2,969	-2,969
F&E costs	63,136	83,669	-20,533
Maintenance	230,903	212,900	18,003
Training	17,715	12,822	4,893
Total	$3,864,088	$3,445,222	$418,866

2. No Sector Reduction Allowed

An even more conservative projection of sector reduction is based on the assumption that the number of sectors cannot be reduced from an existing level. Thus, as shown in Figure 15, during and after the implementation of ETABS the number of sectors remains constant until rising traffic forces the addition of new sectors in the same pattern as in the base case. The breakdown of the costs and savings for this transition scenario are shown in Table 33. In this scenario the controller staffing costs are significantly higher than in the base case and the

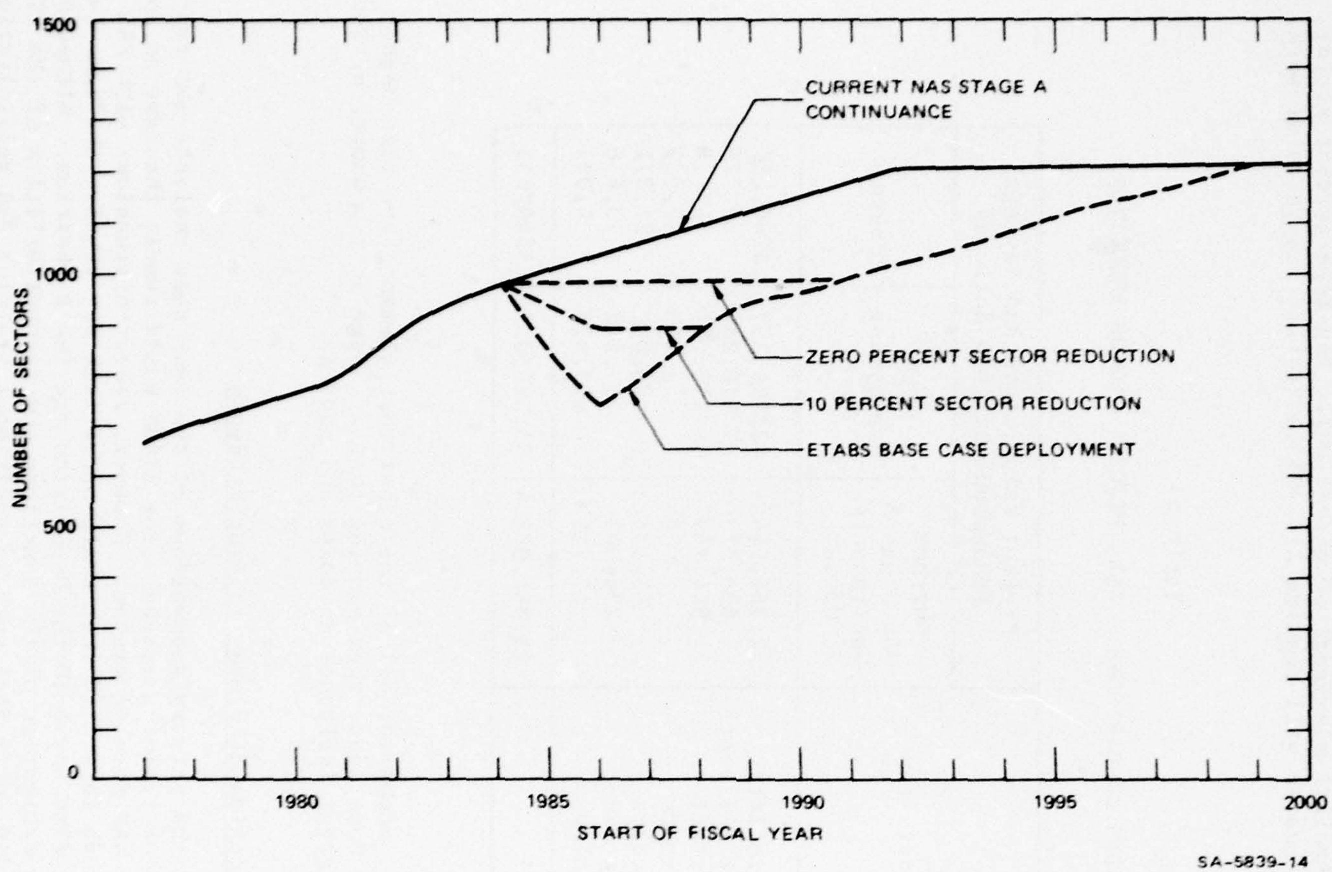

FIGURE 15 ETABS TRANSITION IMPACTS ON SECTOR REQUIREMENTS

savings are, of course, less. This happens because the number of sectors does not decrease at a higher rate than the reduction of the controller work force through attrition. Thus, in order to staff these sectors, more new controllers have to be hired than in the base case. For the entire study period, the base case ETABS system is projected to require 205,022 controller man-years of effort while the zero-percent sector reduction scenario will require 212,303 controller man-years of work.

Table 33

COSTS COMPARISONS: ZERO-PERCENT SECTOR REDUCTION

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,361,544	$2,095,257	$266,287
Other AAT staff	636,023	570,244	65,779
AAF staff	554,767	538,651	16,116
E&D costs	0	2,969	-2,969
F&E costs	63,136	86,007	-22,871
Maintenance	230,903	217,247	13,656
Training	17,715	13,678	4,037
Total	$3,864,088	$3,524,053	$340,035

In this scenario, all of the other cost elements are also higher than in the base case, thus showing that a change in the number of sectors has a great influence on costs and savings.

B. Modification of D-man Training Schedule

One of the primary assumptions of the base case analyses was that the controller training schedule for ETABS would remain the same as for the present NAS Stage A system. However, recent discussions with FAA personnel have indicated that ETABS operations may require the same level of qualification for both the D position and the R position. Although previous investigation of the functions and responsibilities of the ETABS D position did not reveal such an additional training and qualification requirement, its effect on the costs and savings associated with ETABS is examined. This sensitivity analysis assumes that, under an ETABS

environment, the training time required to first qualify to work at at least one D position would be the same as for an R position. This qualification occurs, at the earliest, three years after a developmental controller begins training (as shown in Table 20), although the full training cycle is four years. The effect of this assumption on projected costs and savings during the study period was not very substantial (Table 34). There was only an 11 million discounted dollar difference between the projection of costs and savings. This small difference is primarily due to the large number of controllers who are already radar qualified at the time of ETABS implementation.

Table 34

COSTS COMPARISONS: MODIFIED TRAINING SCHEDULE FOR ETABS D-MAN

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,361,544	$2,051,773	$309,771
Other AAT staff	636,023	551,932	84,091
AAF staff	554,767	530,680	24,087
E&D costs	0	2,969	-2,969
F&E costs	63,136	82,255	-19,119
Maintenance	230,903	209,024	21,879
Training	17,715	13,121	4,594
Total	$3,864,088	$3,441,754	$422,334

C. Three-year Deferral of ETABS Purchase and Installation

The time required for the development, testing, and implementation of new technology is often one of the most uncertain factors. Deployment can be delayed by such factors as material shortages, development problems, unavailability of capital investment funds, or a delay in finalizing the go-ahead decision. Because of this potential for delay, it seems appropriate to examine how sensitive the results of the analyses are to a slippage in the ETABS purchase and installation schedule. This

case analyzed how a 3-year deferral of the initial purchase and installation of ETABS would affect the projections of system costs and savings. In the interest of a conservative analysis of ETABS costs, the initial development costs were not deferred in this analysis so that discounting effects would not reduce ETABS F&E present values. The results of this investigation are shown in Table 35.

Table 35

COSTS COMPARISONS: 3-YEAR ETABS DEFERRAL

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	\$2,361,544	\$2,144,369	\$217,175
Other AAT staff	636,023	585,631	50,392
AAF staff	554,767	541,700	13,067
E&D costs	0	2,969	-2,969
F&E costs	63,136	86,118	-22,982
Maintenance	230,903	219,425	11,478
Training	17,715	14,014	3,701
Total	\$3,864,088	\$3,594,226	\$269,862

D. Traffic Forecasts

The development of controller and sector requirements for each year during the study period was based on the traffic activity forecast for that year. For this reason, the sensitivity of the base case projections of costs and savings to variations in the traffic forecasts was examined. Table 36 details the cost and savings projections for the case where traffic activity grows at only 50 percent of the forecast values. Table 37 shows how these projections would be affected if the traffic growth is 50 percent greater than forecast. Notice that such variations in traffic activity can significantly affect the costs or expenditures associated with both the current NAS Stage A system continuance as well as ETABS deployment. Despite the large variation in costs, however, the savings projected for ETABS exhibit little change over these levels of traffic activity.

Table 36

COSTS COMPARISONS: TRAFFIC DECREASES 50 PERCENT

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,016,508	$1,702,411	$314,097
Other AAT staff	588,267	518,715	69,552
AAF staff	524,201	495,361	28,840
E&D costs	0	2,969	-2,969
F&E costs	39,449	39,087	362
Maintenance	199,599	172,095	27,504
Training	12,485	7,711	4,774
Total	$3,380,509	$2,938,349	$442,160

Table 37

COSTS COMPARISONS: TRAFFIC INCREASES 50 PERCENT

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,585,818	$2,230,099	$355,719
Other AAT staff	667,294	588,934	78,360
AAF staff	571,510	555,837	15,673
E&D costs	0	2,969	-2,969
F&E costs	75,541	110,299	-34,758
Maintenance	248,051	235,077	12,974
Training	20,814	15,550	5,264
Total	$4,169,028	$3,738,765	$430,263

The gain in savings due to ETABS is greater with the 50 percent reduction in traffic growth than with the 50 percent increase. These results are due in part to the effect on F&E costs of the traffic growth variations. Under the 50 percent reduced growth assumption, F&E savings are greater than baseline savings because the acquisitions of additional sectors are deferred, and fewer NAS Stage A type sectors need be replaced by ETABS. By delaying F&E expenditures for more ETABS sectors, their present value cost equivalent is reduced by the discounting calculations. Under the 50 percent increased growth assumption, ETABS sector acquisitions are accelerated, and ETABS F&E costs are increased relative to the base case deployment.

E. Staffing Salary Costs

The projected staffing costs can be affected by variations in the staffing salary costs. Table 38 shows the effect of a 25-percent increase in the staffing salary costs for both AAT and AAF personnel. The effect of wage reductions was not examined because the reductions are considered unlikely.

Table 38

COSTS COMPARISONS: 25-PERCENT INCREASE IN STAFFING COSTS

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,951,930	$2,541,021	$410,909
Other AAT staff	795,029	699,878	95,151
AAF staff	693,459	663,350	30,109
E&D costs	0	2,969	-2,969
F&E costs	63,136	82,255	-19,119
Maintenance	230,903	209,024	21,879
Training	17,715	12,773	4,942
Total	$4,752,172	$4,211,270	$540,902

F. E&D and F&E Costs

The sensitivity of the base case results to changes in E&D and F&E costs was also examined. This is a particularly important analysis of sensitivity because of the difficulties associated with developing accurate E&D and F&E cost estimates of a subsystem that has been only functionally defined. A breakdown of the costs and savings associated with a 25 percent increase in ETABS E&D and F&E costs is shown in Table 39.

Table 39

COSTS COMPARISONS: 25-PERCENT E&D, F&E COSTS

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,361,544	$2,032,817	$328,727
Other AAT staff	636,023	559,902	76,121
AAF staff	554,767	530,680	24,087
E&D costs	0	3,711	-3,711
F&E costs	63,136	102,819	-39,683
Maintenance	230,903	209,024	21,879
Training	17,715	12,773	4,942
Total	$3,864,088	$3,451,726	$412,362

A summary of the costs and savings for different percentage increases in E&D and F&E costs is shown in Table 40.

Table 40

SUMMARY OF ETABS E&D AND F&E COST SENSITIVITY ANALYSIS

ETABS E&D and F&E Cost Increase	Present Value Costs and Savings (thousands of 1976 dollars)	
	ETABS Cost	Savings
25 percent	$3,451,726	$412,362
50 percent	3,473,032	391,056
75 percent	3,494,338	369,750
100 percent	3,515,644	348,444

G. No Controller Workload Reduction

In the base case analyses, cost savings associated with ETABS were primarily related to the reduction of controller workload and the elimination of the A position. ETABS reduction of the amount of controller workload for a given level of traffic activity increased the traffic handling capabilities of the individual controllers and sectors, thereby reducing or forestalling the need for new sectors and controllers. The elimination of the need for A positions enables the R and D controllers who have been manning these positions to work at the positions that are more commensurate with their qualifications, thereby increasing the effective number of qualified R and D controllers.

In order to assess the degree to which the base case projections of ETABS costs and savings is influenced by controller workload reduction, this sensitivity analysis assumed that ETABS does not reduce controller workload at all. Using this assumption, both ETABS and the current NAS Stage A system would have the same requirements for R controllers, D (and equivalent) controllers, and en route sectors. The only difference between the two systems would be the elimination of the A position for ETABS. This situation can be considered as a worst case scenario, since the only ETABS benefit assumed is the elimination of the need to man A positions. Even under this conservative assumption, the implementation of ETABS is projected to save the FAA nearly $143 million during the study period (see Table 41).

Table 41

COSTS COMPARISONS: A-MAN REDUCTION ONLY

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,361,544	$2,231,679	$129,865
Other AAT staff	636,023	602,298	33,725
AAF staff	554,767	548,081	6,686
E&D costs	0	2,969	-2,969
F&E costs	63,136	92,334	-29,198
Maintenance	230,903	227,199	3,704
Training	17,715	16,634	1,081
Total	$3,864,088	$3,721,199	$142,894

H. Peaked Traffic Demand Profile

The base case analysis and all of the preceeding sensitivity analyses have assumed that the forecast growth in traffic will result in a smoother traffic demand pattern. That is, as the traffic level increases a disproportionate amount of the increased demand will occur during the nonpeak hours, thereby reducing severe fluctuations in the demand level over the day. This smoothed distribution of the increased traffic demand over the 8-hour study period does not reduce the total traffic demand.

In this sensitivity analysis we examined the effect of the traffic demand pattern on the analysis results by using a peaked traffic pattern where the forecast traffic increases are scaled in direct proportion to the current distribution of traffic. In this analysis all other factors were held constant (that is, the same as in the base case analysis). The projected costs and savings for this scenario are shown in Table 42. The peaked traffic distribution requires more sectors and more controllers to handle a given traffic level than would a smoothed traffic distribution.

Table 42

COSTS COMPARISONS: PEAKED TRAFFIC DEMAND PROFILE

Cost Item	Present Value Costs and Savings (thousands of 1976 dollars)		
	Current NAS Stage A Continuance Costs	ETABS Deployment Costs	Savings
Controllers	$2,598,050	$2,221,949	$376,101
Other AAT staff	668,645	584,184	84,461
AAF staff	571,188	553,496	17,692
E&D costs	0	2,969	-2,969
F&E costs	75,287	91,184	-15,837
Maintenance	247,696	232,706	14,990
Training	20,980	15,089	5,891
Total	$4,181,846	$3,701,517	$480,329

I. <u>Summary of the Sensitivity Analyses</u>

A summary of the sensitivity analyses is tabulated in Table 43. An evaluation of these sensitivity analyses shows that the savings due to ETABS is most highly affected by the assumption that ETABS will not reduce controller workload requirements. However, even in this worst case scenario the projected savings due to the development and use of ETABS is nearly 143 million discounted dollars. This projected savings is nearly 4 percent of the NAS Stage A costs projected for the study period and should justify the continued development of ETABS.

Projected savings are also sensitive to the assumption that the number of en route sectors cannot be reduced during or after ETABS deployment. Even using this conservative assumption, however, ETABS is projected to save more than $340 million, or nearly 9 percent of the projected current NAS Stage A continuance costs.

A 25-percent increase in staffing costs also significantly influences the projected savings, increasing projected savings by almost 25 percent over the base case. The savings of over $540 million are more than 11 percent of the projected costs for current NAS Stage A system continuance. While a corresponding decrease in staffing costs would probably reduce

Table 43

SUMMARY OF THE SENSITIVITY ANALYSES

Variation	Sensitivity Analysis Description	Current NAS Stage A Continuance Costs	Change from Base Case	ETABS Deployment Costs (thousands of 1976 dollars)	Change from Base Case	Savings (thousands of 1976 dollars)	Change from Base Case
1	Base Case	$3,864,088	0.0%	$3,430,420	0.0%	$433,668	0.0%
2	10% sector reduction allowed	3,864,088	0.0	3,445,222	0.4	418,866	-3.4
3	0% sector reduction allowed	3,864,088	0.0	3,524,053	2.7	340,035	-21.6
4	D-man training schedule	3,864,088	0.0	3,441,754	0.3	422,334	-2.6
5	Three-year deferral of ETABS	3,864,088	0.0	3,594,226	4.8	269,862	-37.8
6	50% decrease in traffic increase	3,380,509	12.5	2,938,349	-14.3	442,160	2.0
7	50% increase in traffic increase	4,169,028	7.9	3,738,765	9.0	430,263	-0.8
8	25% increase in staffing costs	4,752,172	23.0	4,211,270	22.8	540,902	24.7
9	25% increase in E&D, F&E costs	3,864,088	0.0	3,451,726	0.6	412,362	-5.2
10	No controller workload reduction	3,864,088	0.0	3,721,199	8.5	142,894	-67.0
11	Peaked traffic profile	4,181,846	8.2	3,701,517	7.9	480,329	10.8

the projected base case savings, it is unlikely that such a decrease will occur. On the other hand, staffing costs have already been increased since these analyses were performed.

The projected savings associated with ETABS is also significantly affected by the deployment schedule. As shown in Table 43, a 3-year deferral of ETABS implementation would reduce the projected savings to less than $270 million, nearly a 40-percent decrease.

The remaining sensitivity analyses have shown little change from the base case savings projection. When considering the results of the entire analyses it is evident that the ETABS concept has a significant potential for decreasing FAA costs during the FY 1977-99 period.

Appendix A

ROUTINE WORKLOAD MODELING

Appendix A

ROUTINE WORKLOAD MODELING

This appendix illustrates RECEP-based routine workload modeling, using as examples the team model formulations for current NAS Stage A system 1A (2.5-man team) and ETABS system 2 (2-man team). Routine workload modeling, as well as potential conflict processing and surveillance workload modeling, is described at length in Refs. 1 through 4. Those reports address both team and R-controller-only models for 2-man, 2.5-man, and 3.5-man sector operations. The material in this appendix is excerpted from the Atlanta Center case study report,[2] and is intended to be a brief introduction to workload modeling.

The RECEP routine work-load formulations are based on observed data describing routine task execution times and task frequencies. Since ETABS effects are modeled by adjusting task execution times, the following paragraphs describe the methodology used to enumerate tasks and task times.

1. System 1A (NAS Stage A) Routine Events

Routine control events carried out by the R and D controllers of the NAS Stage A 2.5-man sector team operation are listed in Table A-1. The events are categorized according to five functions: A/G communications, FDP/RDP operations, flight strip operations, interphone communications, and direct voice communications. The control jurisdiction transfer is the collection of control events required to hand off an aircraft from one sector to another. Traffic structuring refers to the procedural-based, decision-making process of guiding aircraft through a sector. Pilot requests result in real-time flight modifications, adding work. Pointouts are actions required by a sector team to retain control of aircraft briefly in or near another's airspace. General intersector coordination includes those informational transfers that are performed to keep cognizant of multi-sector traffic movement, but are not part of handoff, traffic structuring, pilot request, or pointout activities. General system operation refers to the remaining activities not included in the above catagories, activities such as equipment operation and flight data maintenance.

Each control event in Table A-1 is described in terms of the minimum performance times required to execute A/G communication, FDP/RDP* data

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*FDP/RDP operations refer to flight data processing/radar data processing operations which is the terminology used in the previous study reports to describe computer data entry and display tasks.

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Table A-1

R-D TEAM ROUTINE EVENT MINIMUM PERFORMANCE TIME ESTIMATES, 2.5-MAN SECTOR OPERATION, SYSTEM 1A--NAS STAGE A BASE

Routine Control Event Description		Minimum Task Performance Time* (man-second per task)					Minimum Event Performance Time (man-seconds per event)
Event Function	Basic Event and Supplemental Event	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication†	
Control jurisdiction transfer	Handoff acceptance	--	2	1	--	--	3
	Flight data update	--	3	--	--	--	3
	Intersector coordination	--	--	--	7	6	13
	New flight strip preparation	--	--	10	--	--	10
	Handoff initiation-automatic	--	--	1	--	--	1
	Manual initiation-silent	--	3	--	--	--	3
	Intersector coordination	--	--	--	7	6	13
Traffic structuring	Initial pilot call-in	4	--	1	--	--	5
	Flight data altitude insert	--	3	1	--	--	4
	Altitude instruction	4	--	2	--	--	6
	Flight data altitude amendment	--	3	--	--	--	3
	Intersector coordination	--	--	--	5	6	11
	Heading instruction	5	--	2	--	--	7
	Flight data amendment	--	10	--	--	--	10
	Intersector coordination	--	--	--	5	6	11
	Speed instruction	5	--	2	--	--	7
	Intersector coordination	--	--	--	5	6	11
	Altimeter setting instruction	3	--	1	--	--	4
	Runway assignment instruction	3	--	--	--	--	3
	Pilot altitude report	5	--	2	--	--	7
	Flight data altitude insert	--	3	--	--	--	3
	Pilot heading report	5	--	2	--	--	7
	Pilot speed report	5	--	2	--	--	7
	Traffic advisory	4	--	--	--	--	4
	Transponder code assignment	4	--	--	--	--	4
	Flight data code amendment	--	3	2	--	--	5
	Miscellaneous A/G coordination	5	--	--	--	--	5
	Frequency change instruction	4	--	1	--	--	5
	Intersector coordination	--	--	--	4	6	10
Pilot request	Altitude revision	6	--	2	--	--	8
	Flight data altitude amendment	--	3	--	--	--	3
	Intersector coordination	--	--	--	5	6	11
	Route/heading revision	8	--	2	--	--	10
	Flight data route amendment	--	10	--	--	--	10
	Intersector coordination	--	--	--	6	8	14
	Speed revision	6	--	2	--	--	8
	Clearance delivery	20	3	2	--	--	25
	Miscellaneous pilot request	8	--	--	--	--	8
Pointout	Pointout acceptance	--	--	--	7	8	15
	Data block suppression	--	3	--	--	--	3
	Pointout initiation	--	3	2	7	8	20
General intersector coordination	Control instruction approval	--	--	--	5	6	11
	Planning advisory	--	--	--	5	6	11
	Aircraft status advisory	--	--	--	5	6	11
	Control jurisdiction advisory	--	--	--	6	6	12
	Clearance delivery	--	--	2	20	6	28
	Flight data update	--	3	--	--	--	3
General system operation	Flight data estimate update	--	1	3	--	--	4
	Data block/leader line offset	--	2	--	--	--	2
	Data block forcing/removal	--	3	--	--	--	3
	Miscellaneous data service	--	3	--	--	--	3
	Flight strip sequencing/removal	--	--	2	--	--	2
	Equipment adjustment	--	3	--	--	--	3

*Task performance time estimates are based on data collected at the Los Angeles Center.

†Indicated value is double the measured direct voice communication time duration.

entry and display operations, flight strip processing, interphone communication, and direct (face-to-face) voice communication tasks. The individual task performance times in Table A-1 are stopwatch measurements of minimum execution times observed during the case studies.[1,2]

The basic events of Table A-1 are the performance items necessary for event execution; supplemental events are performed only when required. For example, under the control jurisdiction transfer function, the basic handoff acceptance event is performed silently and requires 2 man-seconds of FDP/RDP keyboard or trackball manual operation to affect the handoff and 1 man-second of flight strip manual marking to record its occurrence. In some cases, supplemental FDP keypunch operations are necessary to input additional flight data. For instance, a sector team receiving an aircraft taking off from a non-ARTS III-equipped terminal control facility would input an airport departure message to update the FDP data file. This latter action, which requires 3 man-seconds, is an additional activity, bringing the total time to 6 man-seconds of sector teamwork for these activities. A supplemental intersector coordination accompanying the basic silent handoff typically requires a 7-second interphone communication and 3-second oral message relay or consultation between the R and D controllers. Since the oral consultation simultaneously consumes 3 seconds of both controllers' time, this direct voice communication requires 6 man-seconds of sector team work, which is shown in Table A-1. On rare occasions, an unexpected aircraft "pop-up" requires manual preparation of a new paper flight strip, which consumes an additional 10 man-seconds.

The basic handoff initiation event is automatically performed by the NAS Stage A computer system when an aircraft arrives at some predefined location (preset by program parameters) at or near sector boundaries, and requires only 1 man-second of flight strip manual marking by a controller. The supplemental 3 man-second manual initiation occurs when a controller prefers to hand off the aircraft at some location other than that specified by the automatic handoff parameters.

All traffic structuring and pilot request basic events are initiated by an A/G communication and generally include some form of flight strip marking. The performance time of each A/G communication task, which entails negotiation and confirmation between pilot and controller, is measured from the beginning transmission to the ending transmission for both parties and includes time devoted to decision making. Similarly, interphone and direct voice communication includes both decision-making and transmission time.

Flight strip marking is of two types: confirmation or recording of a specific event by means of a written check mark or circle on the flight strip, which takes 1 man-second, and data updating, writing numeric speed, altitude, heading, or beacon code revision on the flight strip, which takes 2 man-seconds. In cases where altitude clearances do not conform to current flight plans, the FDP flight data file is amended by manual keyboard entry. FDP operations of this kind typically consume 3 man-seconds, but more elaborate entries, such as route data amendment, take longer.

Although these manual task descriptions are characteristic, two exceptions are noted under the general system operation function. The flight data estimate update event requires the D controller to accept, by means of a 1-second manual button-pushing operation, the FDP computer-generated flight data messages on his computer readout device (CRD), and to copy the displayed information (for example, aircraft expected arrival time, airport departure time, altitude, or beacon code revisions); it takes at least 3 seconds to hand-copy these data onto proposal flight strips. The 2-second flight strip sequencing/removal event refers to the on-line manual arranging and ordering of strips.

Data describing the frequency of occurrence of each basic and supplemental event were collected for selected sectors during each case study. These data, which vary from sector to sector, are tabulated[1,2] in terms of the number of event occurrences per aircraft per hour.

2. System 2 (ETABS) Routine Events

Use of ETABS would affect R and D controller work by altering the task performance times shown in Table A-2. (System 1A task times are indicated in parentheses if they are affected by ETABS.) For example, the FDP computer system is capable of recognizing handoff initiation and acceptance events and automatically indicating their occurrence on a tabular display of flight data for each aircraft. This capability eliminates the 1-man-second manual recording on flight strips of a handoff event. However, preparation of new flight files for unexpected aircraft pop-ups must still be performed (obtained from Table A-1 by transforming the associated 10-man-second flight strip processing into an FDP operation of equal time duration). Silent handoff initiation could be manually performed by a 1-man-second button pushing operation on the aircraft's electronic flight data tabulation, rather than the current 3-man-second FDP/RDP operation.

For traffic structuring and pilot request events, the R controller's flight strip processing tasks become a D-controller FDP operations. Event recording tasks (that is, recording the occurrence of pilot call-in, altimeter setting, or frequency change instruction) are assumed to be accomplished by simple direct entry devices on the tabular display; they would not take longer than the current (flight strip) performance times of 1 man-second each. Since current FDP data entries require 3 man-seconds to perform the necessary keyboard operations, this value is assumed to apply to data entry operations using the tabular display. Therefore, implementation of the tabular display would actually increase data entry operations by 1 man-second compared to those operations currently requiring flight strip entries (which take 2 man-seconds). The 3-man seconds data entry time may be a pessimistic estimate if one considers the possibility of designing improved man-machine interaction devices as part of the tabular display, but it is nevertheless adopted for lack of more precise data. The FDP operations required for accepting handoffs could also give a visual signal (for example, blinking light) from the

Table A-2

R-D TEAM ROUTINE EVENT MINIMUM PERFORMANCE TIME ESTIMATES, 2-MAN SECTOR OPERATION, SYSTEM 2--ETABS

Routine Control Event Description		Minimum Task Performance Time* (man-seconds per task)					Minimum Performance Time (man-seconds per event)
Event Function	Basic Event and Supplemental Event	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication†	
Control jurisdiction transfer	Handoff acceptance	--	2	0 (1)	--	--	2 (3)
	Flight data update	--	3	--	--	--	3
	Intersector coordination	--	--	--	7	6	13
	New flight strip preparation	--	10 (0)	0 (10)	--	--	10
	Handoff initiation--automatic	--	--	0 (1)	--	--	0 (1)
	Manual initiation--silent	--	1 (3)	--	--	--	1 (3)
	Intersector coordination	--	--	--	7	6	13
Traffic structuring	Initial pilot call-in	4	1 (0)	0 (1)	--	--	5
	Flight data altitude insert	--	3	0 (1)	--	--	3 (4)
	Altitude instruction	4	3 (0)	0 (2)	--	--	7 (6)
	Flight data altitude amendment	--	0 (3)	--	--	--	0 (3)
	Intersector coordination	--	--	--	5	6	11
	Heading instruction	5	3 (0)	0 (2)	--	--	8 (7)
	Flight data amendment	--	10	--	--	--	10
	Intersector coordination	--	--	--	5	6	11
	Speed instruction	5	3 (0)	0 (2)	--	--	8 (7)
	Intersector coordination	--	--	--	5	6	11
	Altimeter setting instruction	3	1 (0)	0 (1)	--	--	4
	Runway assignment instruction	3	--	--	--	--	3
	Pilot altitude report	5	3 (0)	0 (2)	--	--	8 (7)
	Flight data altitude insert	--	0 (3)	--	--	--	0 (3)
	Pilot heading report	5	3 (0)	0 (2)	--	--	8 (7)
	Pilot speed report	5	3 (0)	0 (2)	--	---	8 (7)
	Traffic advisory	4	--	--	--	--	4
	Transponder code assignment	4	--	--	--	--	4
	Flight data code amendment	--	3	0 (2)	--	--	3 (5)
	Miscellaneous A/G coordination	5	--	--	--	--	5
	Frequency change instruction	4	1 (0)	0 (1)	--	--	5
	Intersector coordination	--	--	--	4	6	10
Pilot request	Altitude revision	6	3 (0)	0 (2)	--	--	9 (8)
	Flight data altitude amendment	--	0 (3)	--	--	--	0 (3)
	Intersector coordination	--	--	--	5	6	11
	Route/heading revision	8	3 (0)	0 (2)	--	--	11 (10)
	Flight data route amendment	--	10	--	--	--	10
	Intersector coordination	--	--	--	6	8	14
	Speed revision	6	3 (0)	0 (2)	--	--	9 (8)
	Clearance delivery	20	3	0 (2)	--	--	23 (25)
	Miscellaneous pilot request	8	--	--	--	--	8
Pointout	Pointout acceptance	--	3 (0)	--	0 (7)	0 (8)	3 (15)
	Data block suppression	--	3	--	--	--	3
	Pointout initiation	--	3	0 (2)	0 (7)	0 (8)	3 (20)
General intersector coordination	Control instruction approval	--	--	--	5	6	11
	Planning advisory	--	--	--	5	6	11
	Aircraft status advisory	--	--	--	5	6	11
	Control jurisdiction advisory	--	--	--	6	6	12
	Clearance delivery	--	--	0 (2)	20	6	26 (28)
	Flight data update	--	3	--	--	--	3
General system operation	Flight data estimate update	--	1	0 (3)	--	--	1 (4)
	Data block/leader line offset	--	2	--	--	--	2
	Data block/forcing/removal	--	3	--	--	--	3
	Miscellaneous data service	--	3	--	--	--	3
	Flight strip sequencing/removal	--	--	0 (2)	--	--	0 (2)
	Equipment adjustment	--	3	--	--	--	3

*Revised System 1A performance times are indicated in parentheses.

†Indicated value is double the measured direct voice communication time duration.

aircraft's flight data tabulation, which could be negated by pushing a button on issuance of the radio frequency change. We assume that a 1-man-second manual button push would replace the current 1-man-second flight strip marking associated with a frequency change instruction.

Although FDP/RDP keyboard pointout currently forces a data block display onto the recipient sector's PVD, no similar means is available to silently accept the pointout. The receiving sector has no flight strip on the aircraft in question, and verbal intersector communications are used to transmit needed flight data as well as to confirm pointout recognition. This data transferral could be effected by simultaneously forcing pertinent flight data onto the receiving sector tabular display when pointout initiation is performed, thus negating the need for the interphone and associated intrasector voice consultations. As shown in Table A-2, acceptance of the pointout is assumed to be conducted by means of an FDP/RDP operation taking 3 man-seconds.

Important reductions in general system operation work associated with D-controller operations are attributed to the tabular display's potential for eliminating much of the manual flight data estimate update and flight strip sequencing/removal activities. The FDP computer system could automatically transfer flight data updates to the tabular display. The only action required by the D controller would be to acknowledge receipt of the update message--a single action currently taking 1 man-second for button pushing. A computer-driven tabular display would be capable also of automatically sequencing and removing the flight data presentations, thus eliminating the manual flight strip arranging operations currently conducted by the D controller.

Two minor system modifications are meant to eliminate certain activities performed by the R controller to adjust the PVD. These are an automatic data block/leader line offset, and a revised automatic data block forcing/removal. These refinements are peripheral to ETABS design, but are assumed to be implemented in conjunction with the tabular display. Their inclusion in the routine workload model of ETABS does not measurably affect sector capacity and productivity.[3]

The intent of the automatic data block/leader line offset is to eliminate the RDP-related manual keyboard operations performed to reduce PVD clutter caused by overlapping alphanumeric data presentations. The automatic offset feature is estimated to reduce by half the frequency of occurrence of the manual data block/leader line offset event in Table A-2.[2]

At present, radar target data block displays are automatically removed from the PVD according to parameters set for the NAS Stage A system. These parameters specify the time after handoff acceptance at which data blocks are removed from the handoff initiator's PVD. In many cases, the controller initiating handoff would prefer to retain the data block display for a longer time even though an aircraft is no longer under his jurisdiction (for example, so as to be able to distinguish a sector's outgoing from incoming aircraft), and he forces the data block display

back onto his PVD by means of manual RDP keyboard operations. A parameter setting sensitive to the data block display retention requirements of individual sectors would eliminate the frequency of the manual data block forcing/removal event in Table A-2.[a]

3. Routine Workload Weightings

The routine control event data provide a mechanism for estimating the team routine workload associated with a sector flight. Calculated workload weightings for each event are obtained by multiplying event performance times by appropriate event frequencies. The resulting team (R and D controllers) routine workload weightings by selected sectors for the Atlanta Center are summarized in Tables A-3, A-4, and A-5 for systems 1A, 1B, and 2, respectively. The team workload weightings and the R-controller (in parentheses) workload weightings are included in these tables. These data were obtained as part of the Atlanta Center case study.[a]

Table A-3

SUMMARY OF ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEM 1A--NAS STAGE A, 2.5 MAN-TEAM

Sector			Sector Team (R,D) and R-Controller* Routine Workload Weighting (man-seconds per aircraft)					
Type	Identity Number	Name	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication	Total
High en route	36	Allatoona	19.19 (19.19)	11.93 (4.30)	13.94 (5.74)	2.62 (0)	3.02 (1.51)	50.70 (30.74)
Departure transition	37	Crossville	21.67 (21.67)	12.01 (4.69)	16.51 (7.72)	6.39 (0)	7.56 (3.78)	64.14 (37.86)
Departure	38	North Departure	22.07 (22.07)	11.62 (4.30)	18.63 (7.75)	11.58 (0)	12.70 (6.35)	76.60 (40.47)
Arrival	41	Norcross	35.55 (35.55)	13.04 (4.30)	22.18 (12.94)	10.21 (0)	11.40 (5.70)	92.38 (58.49)
Arrival transition	42	Lanier	23.70 (23.70)	10.30 (4.45)	18.30 (8.50)	6.25 (0)	7.40 (3.70)	65.95 (40.35)
Low arrival	46	Commerce	21.79 (21.79)	14.60 (4.30)	18.05 (7.44)	15.75 (0)	15.04 (7.52)	81.23 (41.05)
Low en route	52	Hinch Mountain	24.56 (24.56)	14.62 (4.30)	20.59 (8.25)	23.07 (0)	20.46 (10.23)	103.30 (47.34)

*R-controller work is indicated in parentheses.

Table A-4

SUMMARY OF ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEM 1B--NAS STAGE A, 3.5-MAN TEAM

Sector			Sector Team (R,T) and R-Controller* Routine Workload Weighting (man-seconds per aircraft)					
Type	Identity Number	Name	A/G Communication	FDP/RDP Operation	Flight Strip Processing	Interphone Communication	Direct Voice Communication	Total
High en route	36	Allatoona	19.19 (19.19)	11.64 (1.30)	7.07 (3.66)	0.28 (0)	3.02 (1.51)	41.20 (25.66)
Departure transition	37	Crossville	21.67 (21.67)	11.53 (1.30)	9.07 (4.76)	0.63 (0)	7.56 (3.78)	50.46 (31.51)
Departure	38	North Departure	22.07 (22.07)	10.62 (1.30)	9.63 (5.37)	4.41 (0)	12.70 (6.35)	59.43 (35.09)
Arrival	41	Norcross	35.55 (35.55)	12.51 (1.30)	14.59 (10.00)	1.68 (0)	11.40 (5.70)	75.73 (52.55)
Arrival transition	42	Lanier	23.70 (23.70)	9.60 (1.30)	10.20 (4.60)	1.05 (0)	7.40 (3.70)	51.95 (33.30)
Low arrival	46	Commerce	21.79 (21.79)	10.10 (1.30)	8.69 (5.28)	4.06 (0)	15.04 (7.52)	59.68 (35.89)
Low en route	52	Hinch Mountain	24.56 (24.56)	12.90 (1.30)	9.79 (5.89)	5.11 (0)	20.46 (10.23)	72.82 (41.98)

*R-controller work is indicated in parentheses.

Table A-5

SUMMARY OF ROUTINE WORKLOAD WEIGHTINGS FOR SYSTEM 2--ETABS, 2-MAN TEAM

Sector			Sector Team (R,D) and R-Controller* Routine Workload Weighting (man-seconds per aircraft)					
Type	Identity Number	Name	A/G Communication	FDP-RDP Operation	Flight Strip Processing†	Interphone Communication	Direct Voice Communication	Total
High en route	36	Allatoona	19.19 (19.19)	13.92 (0.30)	0 (0)	2.34 (0)	2.70 (1.35)	38.15 (20.84)
Departure transition	37	Crossville	21.67 (21.67)	16.66 (0.69)	0 (0)	4.85 (0)	5.80 (2.90)	48.98 (25.26)
Departure	38	North Departure	22.07 (22.07)	16.30 (0.30)	0 (0)	8.08 (0)	8.70 (4.35)	55.15 (26.72)
Arrival	41	Norcross	35.55 (35.55)	22.38 (0.30)	0 (0)	8.95 (0)	9.96 (4.98)	76.84 (40.83)
Arrival transition	42	Lanier	23.70 (23.70)	16.55 (0.45)	0 (0)	4.85 (0)	5.80 (2.90)	50.90 (27.05)
Low arrival	46	Commerce	21.79 (21.79)	16.82 (0.30)	0 (0)	15.19 (0)	14.40 (7.20)	68.20 (29.29)
Low en route	52	Hinch Mountain	24.56 (24.56)	19.68 (0.30)	0 (0)	21.81 (0)	19.02 (9.51)	85.07 (34.37)

*R-controller work is indicated in parentheses.

†Flight strip processing is not performed.

Appendix B

MULTISECTOR MODELING DATA

Appendix B

MULTISECTOR MODELING DATA

Supporting data for the multisector modeling are given in Tables B-1 through B-5, based on the case studies performed at the Atlanta and Los Angeles facilities.

Table B-1

ESTIMATED MULTISECTOR CAPACITY AND MANNING: LOS ANGELES CENTER, SMOOTHED TRAFFIC

System	Number of Sectors	Traffic Capacity*	Traffic Factor†	Number of Controllers			
				R	D and T	A	Total
1A. NAS A	9	NA‡	NA‡	NA‡	NA‡	NA‡	NA‡
(2.5 men	10§	NA‡	NA‡	NA‡	NA‡	NA‡	NA‡
per sector)	11	985§	1.0§	11§	11§	5.5§	27.5§
	18	1,050	1.07	18	18	9	45
1B. NAS A	9	NA‡	NA‡	NA‡	NA‡	NA‡	NA‡
(3.5 men	10	1,090	1.11	10	20	5	35
per sector)	11	1,110	1.13	11	22	5.5	38.5
	18	1,190	1.21	18	36	9	63
2. ETABS	9	995	1.01	9	9	0	18
(2 men per	10	1,250	1.27	10	10	0	20
sector)	11	1,380	1.40	11	11	0	22
	18	1,475	1.50	18	18	0	36

NA means not applicable.

*Traffic capacity is traffic handled at baseline (1976) level of delay during the 8-hour study period.

†1976 traffic base is 985 aircraft per 8-hour shift.

‡Traffic capacity of pre-1976 sectorization design is less than current (1976) traffic base.

§1976 baseline (ATF delay = 0.22 minutes per aircraft per day shift).

Table B-2

ESTIMATED MULTISECTOR CAPACITY AND MANNING: ATLANTA CENTER, PEAKED TRAFFIC

System	Number of Sectors	Traffic Capacity*	Traffic Factor†	Number of Controllers			
				R	D and T	A	Total
1A. NAS A (2.5 men per sector)	9	480	0.99	9	9	4.5	22.5
	13	590	1.21	13	13	6.5	32.5
	18	700	1.44	18	18	9	45
1B. NAS A (3.5 men per sector)	9	500	1.03	9	18	4.5	31.5
	13	650	1.34	13	26	6.5	45.5
	18	700	1.44	18	36	9	63
2. ETABS (2 men per sector)	9	650	1.34	9	9	0	18
	13	760	1.56	13	13	0	26
	18	830	1.71	18	18	0	36

*Traffic capacity is traffic handled at baseline (1976) level of delay during the 8-hour study period.

†1976 traffic base is 486 aircraft per 8-hour shift.

Table B-3

ATLANTA CENTER GROWTH FACTOR ESTIMATES: PEAKED TRAFFIC

System	Traffic Factor*	Sector Factor*	Staffing Factors*		
			R	D and T	A
1, NAS A	1.0	1.0	1.0	1.0	1.0
	1.1	1.22	1.22	1.0	1.22
	1.2	1.44	1.44	1.18	1.44
	1.3	1.67	1.67	1.36	1.67
	1.4	1.89	1.89	1.55	1.89
	1.5	2.0	2.0	1.91	2.0
	1.6	2.0	2.0	2.36	2.0
	1.7	2.0	2.0	2.82	2.0
	≥1.80	2.0	2.0	3.27	2.0
2, ETABS	1.0	1.0	1.0	0.82	0
	1.1	1.0	1.0	0.82	0
	1.2	1.0	1.0	0.82	0
	1.3	1.0	1.0	0.82	0
	1.4	1.14	1.14	0.93	0
	1.5	1.33	1.33	1.09	0
	1.6	1.58	1.58	1.30	0
	1.7	1.97	1.97	1.61	0
	≥1.71	2.0	2.0	1.64	0

*1976 base.

Table B-4

ESTIMATED MULTISECTOR CAPACITY AND MANNING: LOS ANGELES CENTER, PEAKED TRAFFIC

System	Number of Sectors	Traffic Capacity*	Traffic Factor†	Number of Controllers			
				R	D and T	A	Total
1A. NAS A	9	NA‡	NA‡	NA‡	NA‡	NA‡	NA‡
(2.5 men	10	NA‡	NA‡	NA‡	NA‡	NA‡	NA‡
per sector)	11	985	1.0	11	11	5.5	27.5
	18	1,035	1.05	18	18	9	45
1B. NAS A	9	NA‡	NA‡	NA‡	NA‡	NA‡	NA‡
(3.5 men	10	1,030	1.05	10	20	5	35
per sector)	11	1,105	1.12	11	22	5.5	38.5
	18	1,170	1.19	18	36	9	63
2. ETABS	9	985	1.0	9	9	0	18
(2 men per	10	1,180	1.2	10	10	0	20
sector)	11	1,380	1.4	11	11	0	22
	18	1,430	1.45	18	18	0	36

NA means not applicable.

*Traffic capacity is traffic handled at baseline (1976) level of delay during the 8-hour study period.

†1976 traffic base is 985 aircraft per 8-hour shift.

‡Traffic capacity of pre-1976 sectorization design is less than current (1976) traffic base.

Table B-5

LOS ANGELES CENTER GROWTH FACTOR ESTIMATES: PEAKED TRAFFIC

System	Traffic Factor*	Sector Factor*	Staffing Factor* R	Staffing Factor* D and T	Staffing Factor* A
1, NAS A	1.0	1.0	1.0	1.0	1.0
	1.1	1.0	1.0	1.86	1.0
	1.2	1.18	1.18	2.36	1.18
	1.3	1.41	1.41	2.82	1.41
	1.4	1.64	1.64	3.27	1.64
	1.5	1.64	1.64	3.27	1.64
	1.6	1.64	1.64	3.27	1.64
	1.7	1.64	1.64	3.27	1.64
	≥1.80	1.64	1.64	3.27	1.64
2, ETABS	1.0	0.82	0.82	0.82	0
	1.1	0.86	0.86	0.86	0
	1.2	0.91	0.91	0.91	0
	1.3	0.95	0.95	0.95	0
	1.4	1.0	1.0	1.0	0
	1.5	1.64	1.64	1.64	0
	1.6	1.64	1.64	1.64	0
	1.7	1.64	1.64	1.64	0
	≥1.71	1.64	1.64	1.64	0

*1976 base.

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